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The air transport system

Mike Hirst

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Foreword

The world of commercial aviation is possibly one of the most complex systems of the industrial era. Facets touch upon the most advanced of electronic and material sciences; leading edge IT systems, both large and small; very competitive marketing requirements; and a worldwide service 24 hours a day accommodating adverse weather, wars and political turmoil. All of this operates from equally complex large expensive airports facilitated by air traffic control with its own difficulties. Simultaneously there are planning and training and supply systems that deliver highly developed machines operated by fully qualified staff. The final product is a high-level, quality customer service with all the associated demands delivered at a price that permits a return on the huge amounts of capital required. As if this list is not enough, overlaying the entire fragmented industry is an extraordinary need for, as near as possible, total safety. There are some other hurdles, which include land planning, a host of national and international agreements, rules and regulations. The final element is the environment with its noise and emissions challenges. As a result of this level of complexity most individuals gain experience and expertise in only one or at most a small number of segments of the industry. Pilots, air traffic controllers and engineers rarely stray into other disciplines. Similarly, regulators, airport planners and IT engineers usually stay within a narrow band of specialization. Mike Hirst, however, based on his lifelong experience, has written a most comprehensive book which crosses all the boundaries and gives excellent insights and guidance in all of the different fields. Very few individuals could have even conceived of tackling this enormous project, but Mike Hirst uniquely has risen to the challenge with passion and dedication. He has produced a piece of work that will have widespread appeal, combining as it does both breadth and depth on the subject. Anyone working in commercial aviation, or who is simply interested in aerospace, will benefit from reading this holistic and detailed offering.

Captain W. D. (Jock) Lowe, PhD, FRAeS
Former Director of Flight Operations, British Airways

Preface

A piece of work that considers such a wide swath of activity does not come from an individual's experience alone. Neither is this a textbook that has addressed a syllabus directly, as the orientation and coverage of the many syllabi that were recommended proved to be so varied that a text with the ability to integrate the students from any of them was an ultimate goal. The idea that it would be a book that would address the widest possible aspects of the air transport scene and how systems thinking could be used to orientate problem-solving in a multi-disciplinary environment was sown by two friends many years ago, and they revisited the topic with such regularity that the memory of it was never likely to lapse. It is to Karl John Rein-Weston, with Boeing Commercial Airplane in Seattle, and Leon Skorczewski, now retired from BAE Systems, that I particularly owe thanks for the encouragement and support they gave.

Many of the perspectives explored were accumulated during periods teaching Air Transport Engineering and Management students at Cranfield University and Airport Planning and Management students at Loughborough University. The postgraduate, undergraduate and short course audiences were always willing to try out new ideas and to bring their own insights, and whether young or old I owe a profound thanks to those whose ideas were often the seeds that grew into the concepts that hold the chapters together. More recently I have been encouraged by colleagues at Airport Planning and Development (APD) Ltd, where day-to-day work has catapulted me into a variety of airports and air transport working environments.

Throughout the air transport industry, friends and supporters from Airbus Industrie and Boeing, Rolls-Royce, British Airways and TUI (formerly Britannia Airways), Birmingham Airport, Dornier Consult (Berlin), Munich Airport, the UK Civil Aviation Authority (CAA), National Air Traffic Services (NATS), Eurocontrol (Brussels), the Global Trade, Transportation and Logistics (GTTL) team at the University of Washington (Seattle) and the Air Transport Group at Swinburne University

(Melbourne) have been able travelling companions in creating a journal that has been an exploration and a route map, and into which their own experiences have also been embedded. There are many others whose interest has been more peripheral, but whose inputs have often been crucial to the execution of concepts, and I will single out the Airline Simulator development team led by Simon Hradecky.

Any author needs an able publishing team behind them, and while takeovers and mergers have intervened, I owe special thanks for the confidence and support of Sheril Leich at Woodhead Publishing, for being alongside, and often ahead of me, in what turned out to be a long development period.

Finally, at home my wife Kaye, and children Adrian and Louise, have endured my disappearing into a word-processing world with a stoicism that deserves more than mere thanks.

Mike Hirst
Loughborough

Bibliography

Abeyratne R I R, *Aviation Trends in the New Millennium*, Ashgate, 2001.

Adkins B, *Air Transport and EC Competition Law*, Sweet & Maxwell, 1994.

Ashford N, Stanton H P and Moore C, *Airport Operations,* 2nd edition, McGraw-Hill, 1999.

Ashford N and Wright P H, *Airport Engineering*, 3rd edition, John Wiley & Sons, Ltd, 1992.

Balfour J, *European Community Air Law*, Butterworth, 1995.

Blanchard R S and Fabrykcy W J, *Systems Engineering and Analysis*, 2nd edition, Prentice-Hall, 1990.

Blow C J, *Airport Terminals*, 2nd edition, Butterworth-Heinemann, 1996.

Button K, Haynes K and Stough R, *Flying into the Future – Air Transport Policy in the European Union*, Elgar, 1998.

Button K, Michalski W and Weiss P, *Future of International Air Transport Policy – Responding to Global Change*, OECD, 1997.

Caves R E and Gosling G D, *Strategic Airport Planning,* Pergamon-Elsevier, 1999.

deNeufville R and Odoni A, *Airport Systems – Planning, Design and Management*, McGraw-Hill, 2003.

Doganis R, Traffic forecasting and the 'Gravity Model'. *Flight,* 29 September 1966, 547–549.

Doganis R, *The Airport Business in the 21st Century*, Routledge, 2001.

Doganis R, *Flying Off Course – The Economics of International Airlines*, 3rd edition, Routledge, 2002.

Ferguson E S, *Engineering and the Mind's Eye*, MIT Press, 1993.

Goelers K-M, *Aviation Psychology – Practice and Research,* Ashgate, 2004.

Graham A, *Managing Airports – An International Perspective*, Butterworth-Heinemann, 2001.

Hale F J, *Introduction to Aircraft Performance, Selection and Design*, John Wiley & Sons, Ltd, 1984.

Hanlon P, *Global Airlines*, Butterworth-Hienemann, 1999.

Harris D and Muir H, *Contemporary Issues in Human Factors and Aviation Safety*, Ashgate, 2002.

Horonjoff R and McKelvey F X, *Planning and Design of Airports*, 4th edition, McGraw-Hill, 1994.

International Civil Aviation Organisation, *International Standards and*

Recommended Practices. Annexes 1 to 17 (available through agents from ICAO, Montreal).

International Air Transport Association (IATA), *Airport Development Reference Manual*, 9th edition, 2004.

Janic M, *Air Traffic Systems Analysis and Modelling – Capacity, Quality of Service and Economics,* Gordon and Breach, 2000.

Kazda A and Caves R E, *Airport Design and Operations*, Pergamon-Elsevier, 2000.

Martin P, *Shawcross and Beaumont on Air Law*, Vols 1–3, Butterworth, 1982.

Moir I and Seabridge A, *Civil Avionics Systems*, Professional Engineering Publishing, 2002.

Moir I and Seabridge A, *Aircraft Systems*, Professional Engineering Publishing, 2001.

Morrel P S, *Airline Finance*, 2nd edition, Ashgate, 2003.

Phillips W F, *Mechanics of Flight*, John Wiley & Sons, Ltd, 2004.

Shaw S, *Airline Marketing and Management*, 4th edition, Ashgate, 1999.

Thom T, *Air Pilot Manual* (Vols 2–6), Airlife, 2002.

Vol. 2: Aviation Law and Meteorology
Vol. 3: Air Navigation
Vol. 4: The Aeroplane – Technical
Vol. 5: Radio Navigation and Instrument Flying
Vol. 6: Human Performance

Wells A T, *Air Transportation: A Management Perspective,* 4th edition, Wadsworth, 2002.

Wells A T, *Commercial Aviation Safety,* 3rd edition. McGraw-Hill, 2001.

Wheatcroft S, *Aviation and Tourism Policies: Balancing the Benefits*, World Tourism Organisation Publication, Van Nostrand Reinold, 1994.

Williams J E D, *The Operation of Airliners*, Hutchinson, 1964.

Williams J E D, *From Stars to Satellites*, Oxford University Press, 1992.

1

More than one answer?

Abstract: This chapter considers how civil aviation has changed the complexion of societies, and as a demand-led business it seems set to continue to grow. Because it is a controversial business this chapter focuses on turning towards holistic processes that can assist in finding enduring and acceptable solutions to operational dilemmas. A simple example is presented and solutions are considered that include a range of air service configurations. Extracted data are used to introduce properties of the air transport system that are explored in more detail throughout the book.

Key words: city pairs, influence of demand, frequency of service versus aircraft size, hub-and-spoke and direct route configurations, airport and airspace demands.

1.1 Introduction: breadth of thinking

If flying was as easy as falling from a tree it would not have taken a million years or more for mankind to learn how to fly. The dream became a reality in the 20th century, and the progress from discovery to the stage it has reached, spanning barely 100 years, has surpassed the dreams of most of the individuals who have ever joined in the pursuit.

Civil aviation is only one branch of aviation, but it is an industry that is vigorous and a relatively young industry; it has changed the complexion of societies. All the indications are that it will continue to grow for the foreseeable future, because it is already popular where it is established and it is yearned for where there is still only limited access to its benefits. However, it is a business that has the attributes of a double-edged sword, able to blight as surely as it can enhance and encourage prosperity. While it is a business that will move ahead for many decades to come, its progress will be at times controversial.

A key reason for presenting an overall view of the air transport system is that it is already a victim of its own success. Alongside general approbation,

it is an industry that also has to look inwards. As the volume of air traffic has grown, so the congestion in airspace and at airports has increased, and the quest for more and more capacity is a dilemma, because in such cases the benefits that air services bring are often viewed, even by the beneficiaries, as unjustifiable. The traditional route for finding solutions is to look towards technology, but a future based on such a single-discipline perspective looks bleak. Civil aviation is a complex system of many parts, and to develop as a whole, many stakeholders of its parts have found that turning towards holistic processes has assisted to find enduring and acceptable solutions to dilemmas. These pages consider how wide-ranging views can evolve from the traditional knowledge of the parts, and consider a process that will assist in the transition from the old to the new perspectives and that will be useful to people at all levels of involvement. It is largely to do with developing breadth of thinking and not in losing sight of anything that is already common knowledge.

The solutions that will evolve can be shaped by industry, as has often been the case in the past, or solely by the pressures that society applies, as is feared will be the case with internationally backed statutes promoting political correctness, or through a concerted effort by industry and society that will promote the way the demand is viewed and innovation is applied. The businesses that make up air transport have to balance their self-interests with these societal constraints if they are to maintain the degree of control they believe is rightly their own.

Inevitably, the customer will be asking for more. The definition of ‘more’ is far from simple, as they can crave more capacity or more service with prescribed qualities, or both, and more besides. Whether these are demands that require more on-board comfort, more agreeable flight times or more point-to-point travel depends largely on societal issues. This is well beyond the immediate scope of aviation per se, but at the same time these issues offer the opportunity to look for innovative solutions. Determining solutions will require thinking in terms of how demand is generated, served and satisfied, which goes a long way beyond the traditional ‘box’.

‘Out of the box’ thinking has become an established nomenclature for ‘systems engineers’ and much of what this new discipline has to offer is reflected in the approaches considered and advocated here. The important first principle to stress is that ‘systems engineering’ is not concerned with engineering in the physical sense. The word ‘engineer’ has roots in the Latin description of ingenuity, and the concepts that are used in ‘systems engineering’ are folded into these ideas, whereby those who create are encouraged to be innovative, or to apply ingenious thought processes, to find solutions that better serve broad needs. Systems engineers can be bankers, economists, philosophers and more, as well as engineers – and the

best problem-solvers in society have always have been 'out of the box' thinkers.

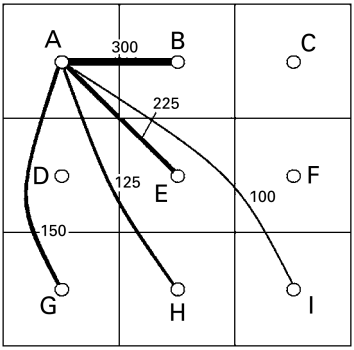
In civil aviation the potential prize is worth the effort, because while many specialists have already learned to branch out from their own fields of interest, there is always a fear that treading even further afield is driven by 'gut feel' and has no justifiable reason. By adopting property-led perspectives, intuitive forays can become structured into objective and justifiable investigations. The outcomes from such curiosity trips become important contributors to opening new perspectives and encouraging the thought processes that are needed to craft solutions to ever more wide-ranging problems. The debate begins simply and grows rapidly into a multi-dimensional web of often contradictory issues, as will be illustrated very quickly in what follows.

1.2 A simple system

The demand for air services (indeed all transportation services) arises from population, its distribution and the economic and other factors that influence the propensity to travel within the population. These are properties of the natural environment. They are never static and they are often unpredictable.

Passengers interact directly with airlines, which offer them a service for the price of a ticket and vie with competitors to win the custom of individuals. Airlines monitor and judge where and when there will be sufficient demand to justify an air service, select aircraft types to serve the demand, create route structures and publish timetables. They use the airports that are available and can, in general, safely assume that the air traffic control (ATC) service providers that guide aircraft while they are airborne will be able to service their needs. This is a brief and generalised description of the route development process, and it is a fact that such important components as the airports and ATC services have little choice but to await the publication of demands that will be placed upon them. This is fine if these providers have the capacity to cope with the proposed level of demand.

However, capacity constraints are unavoidable and just occasionally airports and ATC systems reach their limits and fail the users. They do not fail in the dramatic sense – there is no desire to point at a danger signal. Quite simply, one day there is not the room for any more demand without unacceptable impact on the service, such as delay, as safety takes precedence over capacity. Rather than wait for that time to arrive, it is important that the businesses that make up civil aviation start to think innovatively now, not just about the problem but about the range of possible solutions. Some groups of individuals have started the process, indeed perhaps they all have,



1.1 The assumed inherent demand for transport (passengers/day) between nine regularly spaced and similar-sized communities.

but some are more reluctant than others to enter the fray with their opinions. There should be no desire to oust the old and say 'in with the new'. The aim must be to find out if debate based on wider perspectives offers the chance of finding new paradigms, and the hope has to be that such debate will generate the evidence to assure all interested parties that the industry would be hard pressed to serve communities better.

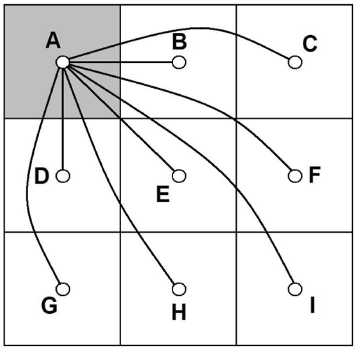
To add practical understanding to the situation and the complexity of the solutions, a very simple system that provides a starting point and is based on a very regularly shaped and homogeneous community will be analysed with regard to several possible ways of serving its travel requirements. It comprises nine identical locations, all equidistantly located, on a three-by-three grid.

The daily demand between city-pairs, based on their distance apart, will be assumed to be as shown in Fig. 1.1.

1.2.1 Service configuration 1

The first scenario to consider is that when a direct 'point-to-point' service is offered between all locations (Fig. 1.2). From any corner location (using A as an example), demand in passengers/day is:

- demand to B = 300
- demand to C = 150
- demand to D = 300
- demand to E = 225
- demand to F = 125
- demand to G = 150
- demand to H = 125
- demand to I = 100 (and the total demand is 1475 passengers/day).



1.2 Service configuration 1: direct services in a nine-airport system.

From any central-edge location (using B as an example), demand in passengers/day is:

- demand to A = 300
- demand to C = 300
- demand to D = 225
- demand to E = 300
- demand to F = 225
- demand to G = 125
- demand to H = 150
- demand to I = 125 (and the total demand is 1700 passengers/day).

From the centre, four locations generate a demand of 225 passengers/day and the other four generate a demand of 300, producing a total demand of 2100 passengers/day. Overall this develops a daily passenger demand of 14 800 passengers and involves 72 one-way services (this is treating A to B as additional to B to A). As might be expected, the busiest airport is at the centre.

If services are planned using a 50-seat aircraft and the desire is to fill 75% of seats in every flight (this can be referred to as a 75% passenger load factor), a number of flights per day can be linked to each passenger flow figure. The 300 passengers/day service can be served by eight flights per day, for example, generating 400 seats and achieving a daily average load factor of exactly 75%. Applying this to the services to/from all the combinations of origin–destination on the grid, the characteristics of the route system can be summarised thus:

- 376 flights daily
- 72 direct (one-way) services, of which on 52 there are 4 or more flights/day and 20 have 3 flights per day.
- 14 800 passengers (average passenger load per flight = 39.4)

Table 1.1 Service configuration 1: service frequency at all airports

	Frequency of flights per day			
	8	6	4	3
Each corner airport	2	1	2	3
Each edge airport	3	2	1	2
Centre airport	4	4	—	—

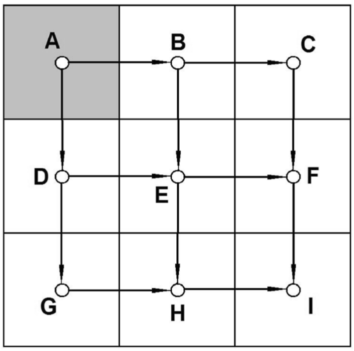
- 'corner' airports handle 1475 passengers and 39 originating flights on 8 routes
- 'edge' airports handle 1700 passengers and 46 originating flights on 8 routes
- the 'centre' airport handles 2100 passengers and 56 originating flights on 8 routes.

The distribution of service frequency at the various airports is shown in Table 1.1. These are characteristics that show the volume and shape, or demand on the various elements of the routes that are the components of the system. The airports are very similarly loaded (78 flights daily at the corners, 92 flights daily at the edges and 112 flights daily at the centre).

1.2.2 Service configuration 2

There are many alternative sets of routes that could be proposed. For example, routes could be arranged horizontally and vertically so that there were no diagonal components in the system, and people could get from A to I, for example, by a number of routes. This is the basis of a further scenario, as shown in Fig. 1.3.

This is a network solution and it is interesting that to get from A to I, there are six possible routes for a user to choose:



1.3 Service configuration 2: network of nine airports

A–B–C–F–I or A–B–E–F–I or A–B–E–H–I

A–D–E–F–I or A–D–E–H–I or A–D–G–H–I

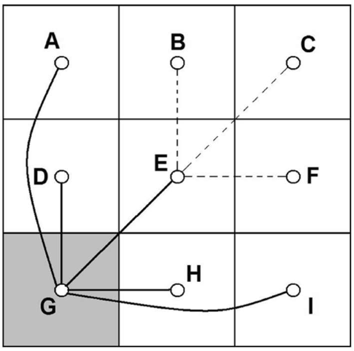
No airline, to this author's knowledge, has ever developed a route structure of a similar nature. This is not dissimilar, however, to the way that surface transport systems (especially railways) often configure their own track-based route systems. Going a long way means lots of stops, and there are passengers disembarking and embarking at every intermediate stop. Trains do not (in most cases) segregate passengers and their baggage, and if the demand exceeds the capacity of the carriages on a train, then passengers stand. Railways cope with this, but airlines cannot.

1.2.3 Service configuration 3

A more likely solution that an airline would prefer arises from deciding that a direct service should be offered only where the daily service frequency on a route exceeds a minimum value, as this will concentrate non-direct demand through a location where demand can be added together to create economic-sized loads and a reasonably frequent service.

If it is considered that four or more daily flights per destination is the desired minimum level of operation, many routes would fail to reach this criterion, and flights would not be offered. Passengers would be directed on to combinations of the routes that remained. Illustratively, Fig. 1.4 shows that the routes radiating from the 'corner' and 'edge' airports, serving the most distant communities, would no longer be operated. That demand would still be there, so alternative routes would involve a connection through the central airport.

Note, however, that because the journeys will take longer (in flying time and because aircraft changes are involved) the demand for the service will diminish. It will be assumed that those operations that attracted 125



1.4 Service configuration 3: limited direct destination choice.

Table 1.2 Service configuration 3: service frequency at all airports

	Frequency of flights per day			
	14	8	6	4
Each corner airport	1	2	—	2
Each edge airport	1	2	2	1
Centre airport	8	—	—	—

passengers/day for direct service will attract only 100 passengers/day, and the 100 passengers/day demand for a flight between diametrically opposite locations will reduce to 75 passengers/day. The effect is to reduce the number of direct services at the outlying airports and to increase the one-way passenger demand level on services to/from the centre airport, which becomes the 'selective hub'.

Using the same aircraft size and load factor criteria to determine service frequency as was used before, the route structure characteristics can now be expressed thus:

- 448 flights daily
- 52 direct (one-way) services, all of which are four or more flights/day
- 16 400 passengers (average passenger load per flight = 36.6)
- 'corner' airports handle 1400 passengers and 38 originating flights on 5 routes
- 'edge' airports handle 1700 passengers and 46 originating flights on 6 routes
- the 'centre' airport handles 4000 passengers and 112 originating flights on 8 routes.

The distribution of service frequency at the various airports is now as shown in Table 1.2. The enormous leap in the statistics applicable to the 'centre' airport is because it has now become the starting point for 1900 additional passengers, who have arrived from elsewhere and are transferring through the airport. They have no reason to be there and no desire to stay there.

The statistics might appear to be exaggerated. However, each 'corner' airport service to the 'centre' now handles 500 passengers (up from 225) and each 'edge' airport service to the 'centre' now also handles 500 passengers (up from 300). The total passengers carried has increased, although some services have become less desirable and demand overall has fallen, to 14 500 passengers, but this apparent contradiction is because 1900 passengers daily start at an outlying airport, fly to the 'centre' airport and then fly on to another outlying airport on a connecting flight.

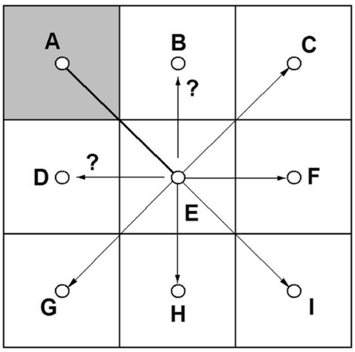
In terms of the impact on the service provision elements of the system, the outlying airports are less busy and have fewer directly served destinations,

but the centre airport handles no more originating passengers and thus will need no additional check-in desks. However, it will need to have a bigger terminal overall to handle the transferring passengers (and baggage). The ATC system has had the number of flights it must handle increased by 19%. While it is delivering fewer passengers overall between their point of origin and ultimate destination, this part of the system has a lot more to do.

An observation was that the flights per day figures rose rapidly on the routes that carried transfer passengers to/from the central airport, to 14 flights per day. This was with a 50-seat aircraft, so an airline might be tempted to consider the use of a larger aircraft with, say, 150 seats. This would not reduce the stress on airport terminals, although it could assist in reducing runway congestion and it would reduce stress on the ATC system. There are other ramifications of such observations, which will come into play as deeper consideration is given to many of the cross-disciplinary factors. For now, the analysis can simply state that such a solution would be practical.

1.2.4 Service configuration 4

A logical extension of the way that the centre airport has been revealed to be a natural place at which passengers can transfer between flights is to examine the impact of an airline using the centre airport as a 'total hub' (Fig. 1.5). In this case, all flights will originate or terminate at the centre airport. A direct consequence of this choice of route structure is that direct flights between adjacent airports are lost, so the 300 passengers/day that plied on each of these 'short' routes will be forced to conduct a journey that is almost three times the distance, in two hops, and thus with additional time added for the transfer at the hub. Even at considerable distances, surface modes of transport (if they are available) will begin to erode the demand for such operations. The 300 passengers/day demand might be reduced so



1.5 Service configuration 4: hub-and-spoke.

Table 1.3 Service configuration 4: service frequency at all airports

	Frequency of flights per day	
	27	22
Four corner airports	—	4
Four edge airports	4	—
One centre airport	4	4

significantly that the transferring passenger numbers will be almost negligible. If it is assumed that demand will fall in such cases to 50 passengers/day, the route structure characteristics – still using a 50-seat aircraft – stack up in this way:

- 392 flights daily
- 16 direct (one-way) services, all of which are 22 or 27 flights/day
- 14 600 passengers (average passenger load per flight = 37.2)
- 'corner' airports handle 825 passengers and 22 originating flights on 1 route
- 'edge' airports handle 1000 passengers and 27 originating flights on 1 route
- the 'centre' airport handles 7300 passengers and 196 originating flights on 8 routes.

The distribution of service frequency at the various airports can now be seen in Table 1.3.

1.2.5 Service configuration 5

Following the argument introduced briefly when the daily frequency was as high as 14 flights/day in the previous example, the airline is almost bound to use a larger aircraft and to reduce frequency again. If a 150-seat aircraft is used the 22 and 27 flight frequency operations reduce to 8 and 9 respectively (still good daily frequencies, in that the chances of a short connection time should still be acceptable), the demand on airspace falls to 146 flights daily. If acceptable connection times are attained, it is fair to assume that the passenger figures will be unaffected.

The attributes determined for the likely service solutions are summarised in Table 1.4. Note that the 'network' was not analysed because it does require considerable judgement regarding the proportions of people that will choose a particular route of the many possible, and the choice of use will be governed by availability. It can be safely assured that such a service mechanism, because it would distribute demand between airports, would exhibit fewer total origin–destination journeys than any other example and

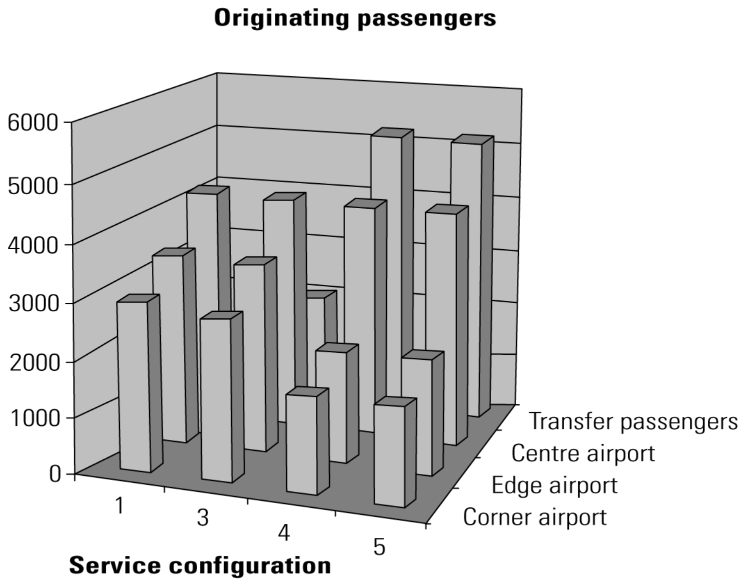
Table 1.4 A comparison of service configuration attributes

	Service configuration				
	1 Direct (50-seat)	2 Network	3 Select-hub (50-seat)	4 Total-hub (50-seat)	5 Total-hub (150-seat)
Overall system					
Flights daily	376		448	392	146
Number of direct (one-way) services	72	Not analysed	52	16	16
Range of frequencies (flights/day)	3–8		4–14	22–27	8–9
Trip passengers	14 800		16 400	14 600	14 600
Average passengers per flight	39.4		36.6	37.2	100
'Corner' airports					
Passengers originating	1450		1400	825	825
Total passengers	2900		2800	1650	1650
Routes	8		5	1	1
Departures per day	39		38	22	8
'Edge' airports					
Passengers originating	1700		1700	1000	1000
Total passengers	3400		3400	2000	2000
Routes	8		6	1	1
Departures per day	46		45	27	9
'Centre' airport					
Passengers originating	2100		2100	2100	2100
Transfer passengers	0		2000	5200	5200
Total passengers	4200		6200	9400	9400
Routes	8		8	8	8
Departures per day	56		108	196	73

the proportion of transfer passengers would be high. Also, potentially, transfer passengers would be evident at all nine airports, but probably still dominantly at the centre.

1.3 Choosing a system solution

While this is a highly theoretical analysis, the outcomes describe, with a remarkable likeness, the situation that exists in air services between communities in most parts of the world. Where hub-and-spoke operations are allowed to dominate, the 'total-hub' or 'selective-hub' airports become



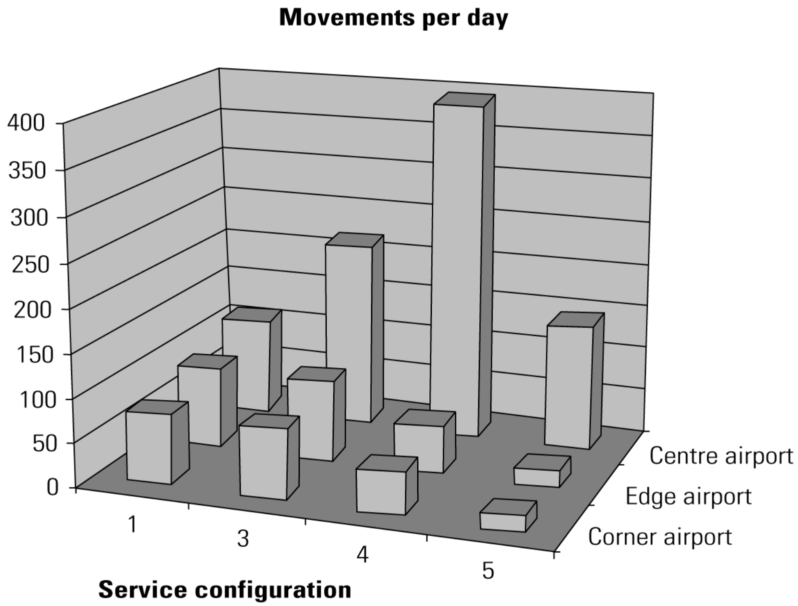
1.6 Service configuration impact on originating passenger numbers.

the busiest airports and the other airports never seem to achieve the potential that they recognise within themselves. These often become characterised as 'major' (increasingly also 'major international') and 'regional' airports respectively. The results in Table 1.4 are shown diagrammatically in Figs 1.6 to 1.8 and their characteristics explored in more detail. They will be food for thought on many accounts given consideration later of how the air transport system can be analysed and its properties expressed.

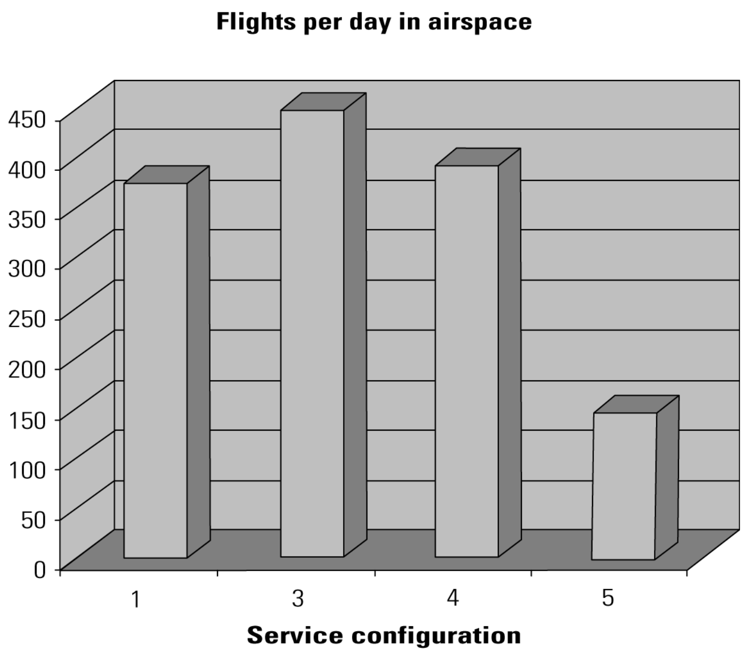
Figure 1.6 summarises the way that originating passenger numbers diminished as the four different scenarios were analysed, and demonstrates that the corner and edge airports were the ones that suffered while the centre airport maintained its healthy share, drawing additional transfer passenger traffic as the route structure moved towards hub-centred configurations.

Figure 1.7 illustrates how the movements per day were identical across all three airport categories in the first service configuration analysed, but they reduced at the corner and edge airports. The movement rate increased at the centre – 'hub' – airport as configurations that introduced transfer passengers were introduced. In the third and fourth configurations the hub is handling every flight – as an inbound or outbound movement – and the total diminishes in the final, right-hand, configuration because a large aircraft has been substituted, thus requiring fewer flights per day to handle the same passenger demand.

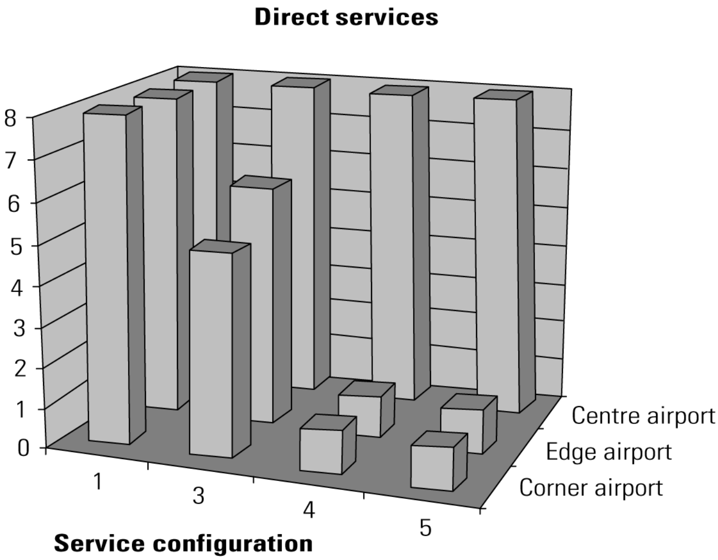
The impact on movements in airspace operations of service configuration



1.7 Service configuration impact on movements at airports.



1.8 Service configuration impact on total airspace movements.



1.9 Service configuration impact on direct services provided.

changes is also significant, as shown in Fig. 1.8. While using the smallest aircraft type considered, the difference between direct, selected-hub and hub-and-spoke operations is relatively small, but the impact of a larger aircraft is almost directly proportional to the increase in seating capacity. Simply expressed, tripling the aircraft size does roughly reduce the number of airspace movements to one-third. Where some discretion is needed in following through this expression is in the situation where, if the larger aircraft costs less per seat-km to run and it therefore contributes to a reduction in fares, demand can be stimulated and the expected movement reduction will be less noticeable. This is an impact mechanism that will become increasingly relevant to discussion in later chapters of the book.

As if losing passengers was not a sad enough outcome for the outlying airports, Fig. 1.9 shows how, when the number of direct service destinations is considered, they suffer the indignity of seeing their destination list fall to the lowest value possible, one, while the hub retains eight destinations, which is the best possible set of route choices in this configuration.

1.4 Service configurations within the real world

In large nations a mid-country airline can sometimes develop in the way that the analysis has shown. When the area being served is opened up, creating interest in an international airline, the possibility of developing routes in almost any direction is more likely. Even airports near to polar regions tend to have preferred directions of travel. The advent of very long-range aircraft

that can overfly the world's ice-caps has diminished this a little, but the problem for operators is that the longer the range of the aircraft, usually the larger it is, and if the demand is not able to support large aircraft these route possibilities do not get exploited.

Consequently, most airlines are nowadays hub-and-spoke based. Large carriers can have several hubs and there are a few airlines that serve a chain of destinations across a long distance with a so-called 'linear' route structure. This has some of the characteristics of a railway service, as passengers will join and leave at each point on the service. This is difficult to associate to demand, and it can be increasingly complicated by the 'freedom' to serve a pair of international destinations that are not the carrier's home-base.

The routes that an airline chooses to serve are therefore often a function of the way the population is distributed, the degree to which the population of the nation in which the airline is based is able to afford to fly, the historical links between the nation and other nations and so on. The preference for a particular set of routes will be determined not just by the intrinsic demand but also by the way that the airline can channel that demand through states with whom its home nation has prior traffic agreements and its own preferred 'hubs'. These can be branching points on its own route structure or the home-base of a collaborative airline. The latter has become a more frequent occurrence since airlines have congregated into 'alliances'.

The way that route structures in reality will differ from those in theoretical terms is governed by influences and by the consequences these have on the airline. The influences require that intrinsic demand is considered in terms of how it is modified by governmental and international regulations, and in some cases by physical factors too. Subsequent airline interest is in how various characteristics of the airline are affected by the service they can envisage. These are 'properties' of the solution, and while airlines are at liberty to make their own choices they will be obliged, or well advised, to consult with other parties whose ability to support their plans will affect their business plan. In the latter category are airports and airspace service providers. Looking inwardly, often an aircraft manufacturer can offer palliatives, largely through aircraft development, that will lessen risk or improve their product's economic capability.

To understand each of these influences and to develop a way of describing their effects on various stakeholders, the chapters that follow have been structured to view influences (treated as 'environments' in which the whole system is submerged) and components (or elements) of the overall system. In the chapters devoted to the latter the properties of each will be developed from knowledge of their own internal processes, with the view that they will reveal similarities that allow their relationships to be expressed more

formally than is currently perceived. Within this framework it is postulated that the challenges of the future, which will affect all stakeholders, can be better studied and expressed.

The influences will be subdivided into three environments:

1. The ‘natural environment’ considers everything related to the Earth: its size and shape, the shape of landmasses, how populations are distributed and the properties of the atmosphere – in terms of physical characteristics and that interminable condition known as the weather – in which aircraft fly. The effects imposed by what are realistic conditions, but irregularities compared with the analysis already conducted, will begin to take shape.
2. In the ‘regulatory environment’ interest is concentrated on the attributes of the legislative processes that govern the behaviour of aviation. Whether nations condone or condemn each other’s company affects the air service agreements between them. Irrespective of politics all operations have to respect safety-related regulations, which again stem from international roots and can have individual character expressed in specific national rules. The pan-national activities that govern such regulations are there to guarantee, so much as legislators can, that safe operations will be a common commodity.
3. Finally, the ‘operational environment’ includes the airports (which are so influential they deserve to be singled out for consideration in more depth) and the many technical devices used to locate, monitor, guide and communicate with aircraft as they fly. The preoccupation in the main is to achieve commonality and consistent – and very high – levels of safety, so that an aircraft fit to fly in one place will be as fit to fly in another place. There is room for diversity and the operational overlaps that have developed create a backdrop against which the technical scene can be explored in more detail.

1.5 Elements of the air transport system

There are four particular ‘elements’ of the air transport system, each of which can be allied to a particular ‘industry’ (or sets of stakeholders). In these, the business-led aspects will be balanced against safety and operational efficiency, and the customer’s service requirements. One way in which service requirements can be compromised has been illustrated readily in the way that the ‘more remote’ communities fared least favourably in the route structures already considered. The way all requirements are considered and the way that decisions are taken in respect of the qualities associated with each element by its respective stakeholders will become influences on individuals in other elements. Each stakeholder group is

accorded a chapter. It is largely conventional managed performance issues, viewed against the wider perspectives that arise from the 'out of the box' approach, that allow deeper consideration of the attributes of the total air transport system.

1.5.1 Airlines

The route configurations considered so far have concentrated on the way that, perhaps, one airline would devise a solution to meet the assumed service demand. It is possible to extend from this simple beginning. For example, in the final situation considered the poor performance between adjacent locations on the periphery actually created an opportunity for small-aircraft (50-seat) operators to offer competitive 'direct' services. They would not overlap with the major hub operator, nor would they need to have schedules coordinated with them and they would have a relatively small impact on the hub airline's passenger figures. In that they would attract some passengers, the hub airline might be willing to see such a service operating. The additional operator would also attract the most difficult to coordinate transfer passengers. There can even be benefits for the hub airline in offering a partnership, for example in terms of getting the major airline's name in front of more regional passengers simply through offering services such as ticketing and reservations to assist the smaller airline to reduce its own overhead costs. The potential in these cases illustrates some of the characteristics that can be seen in the way that small and large airlines interact throughout the world today, with regional airlines often flying in the colours of a local major carrier. The driving forces in this sector of the industry are getting enough revenue to cover costs, and to do this without being driven into a corner by the more aggressive members of the community. They find niches based on markets, on the way they handle the requirements of their clientele and the way they use the equipment and facilities at their disposal.

1.5.2 Airports

The tendency for an airline to prefer using hubs has been shown to have a significant impact on airports. The diminished route choice available to the more remote community is clear from the trend across the summary table. If the hub is only used to attract passengers on the least attractive routes (in terms of daily passenger numbers) the effect on the airline's operation is meagre, but the effect on the hub is already considerable, with transfer passengers rising to around one-third of the total number of passengers in the totals presented in Table 1.4. (A general convention in statistics is that origination and departing passengers are the 'terminal' passengers and each

'transfer' passenger is counted only once at the hub. In terms of airline passengers the transferring passenger does count twice, however, once on each flight. This explains why airline and airport passenger figures often fail to tally.)

In this regard, airports can become the hostage to an airline's desires. A sensible strategy for the airline is to coordinate its plans with the airports that it affects. The airline will do this, but the stance often is quite simply presented on a commercial footing, with the attitude 'We will swell your passenger numbers, so what discount per passenger will we get on our landing and passenger fees?' The airport has to consider the impact of hubbing (as a new or increased activity) as part of its own strategy, for this is a case of where the provider has to invest, but might have to do so without a clear indication that there will be proportional financial benefits. Handling transfer passengers will require a minimum connection time (MCT) to be declared for the airport. If the airport has a complex passenger-handling situation, for example multiple terminals, the attainment of an MCT as short as the airline will almost certainly desire may be an impossible imposition. The handling of transfer passengers often entails keeping both the passenger and baggage flows as simple as possible.

An additional complication is that transfer passengers are not a homogeneous commodity. They can be subdivided into one of four categories, determined by their origin and destination, in terms of whether they are from a domestic or international source and going to a domestic or international destination. The differentiating factors are as follows:

1. *Domestic arrival–domestic departure*. The passenger is arriving from a source where security procedures can be expected to be the same as the transfer and destination airport. The passenger does not need any passport control checks and thus should be able to arrive, proceed to the departure lounge (thus staying 'airside') and would anticipate their baggage being transferred automatically within the baggage sortation system.
2. *Domestic arrival–international departure*. The passenger may have been checked through the hub and thus will not need to proceed 'landside' for check-in at the transfer airport. Similarly, their baggage may have been handled so that it can be transferred automatically within the baggage sortation system. If this is the case, and there are no passport control procedures associated with the destination country that need to be conducted, the passenger can be processed in the same way as a domestic–domestic transfer. Where there are many travellers in this category (a 'gateway-hub' airport) the appropriate facilities may be justifiable, and the airport would expect the airline to support the cost of provision of facilities. Where this is a rare or infrequent pattern, the

passenger might have to collect their baggage from the domestic arrival, proceed to landside and perform the full departing passenger handling process, including check-in, security, passport check, etc. The ability to attain a short MCT is thus reduced.

3. *International arrival–domestic departure*. The passenger invariably has to pass through the inbound immigration/passport control process, and if the departure airport security regime was not acceptable to the regime enforced at the hub airport they might have to collect baggage, pass through customs and arrive 'landside'. Where this affects a substantial proportion of travellers – and this may imply that the passenger has been issued with a boarding pass for their on-going flight – the airport may provide a transfer baggage drop-off point and allow the passenger to proceed immediately to the security process. Even with such facilities a transfer can take a considerable time. This transfer mode can only be simplified in nations where there is a relatively relaxed approach to security.
4. *International arrival–international departure*. Invariably this is a long-winded process. The passenger is 'alien' in terms of incoming and outgoing sectors, and there are few airports where the national security rules would allow a fast-track passage. Most such transfer passengers have to proceed through the complete arriving passenger sequence, emerge landside, transfer to check-in and commence what is a new flight, and under a new set of operating standards. This is by no means a universal situation, however. Some airports, such as those in the Middle East that are keen to be hubs between Europe and Asia, do allow people to be booked through and to pass through a process as simple as the domestic–domestic transfer process, with automatic transfer of baggage in sortation. This is unthinkable in a nation that believes it faces a terrorist threat and subsequently imposes high-security requirements.

Whatever the case, it is clear that the effect on terminal facilities will be, potentially, profound. Situations can arise such as can be found when comparing London Gatwick (used as a hub by a relatively small proportion of passengers only) with Atlanta (much more frequently used as a hub); whereas the latter has almost double the passenger throughput of the former airport, each has a similar number of check-in desks. Atlanta has a larger proportion of the terminal area devoted to waiting areas (departure/gate lounges) and indeed the terminal configuration was designed, in the 1970s, to accommodate the airlines that designate the airport as a hub so that they have adjacent stands. These stands are on satellites (independent piers in fact) and are not a part of the terminal building; within the satellites there is a large circulation space. This saves passenger walking time and a 'local' baggage sortation capability at the ramp allows transfer baggage to be

identified and transferred quickly between gates, rather than being taken into the full baggage sortation system.

Airports designated ‘hubs’ by their main user airlines often have terminals that have developed identical or equivalent systems to that described for Atlanta. Airports do not just handle airlines – they adapt to the traffic that the airlines bring to them. They also become niche organisations and have to balance how to use what they have and what they can afford. They almost mirror the same management dilemmas.

1.5.3 Airspace

In simple terms, the greater the number of movements that occur in a region in a given time, the higher is the likelihood that there will be a need for the air traffic service to impose control, in order to ensure safe separation between movements. The more these constraints are applied, the more the service will be forced to operate non-optimally. Imposing a time limitation, vectoring an aircraft, or imposing a vertical flight condition restriction will introduce ‘delay’ and will also introduce ‘non-optimal’ operating conditions. The fact that a flight takes a little longer, or flies a little lower or slower, has been of little consequence to the passenger, provided that they arrived in a relatively timely manner and the operation was conducted safely. Nowadays those small operational variations will be counted in terms of financial and environmental impact. The heat is on for airspace service providers to devise ways of meeting all the statutory conditions that arise from the regulatory environment, to use the techniques offered by technologies in the operational environment and to minimise the impact of operations on the natural environment.

Beyond the normal operation condition limitations and drawbacks, there is the undeniable risk that, one day, the air traffic system will run out of capacity. This is an issue that has been apparent for a long time, but has been virtually neglected. It is likely to become a mainstream issue on two accounts. First, environmental accountability will be more fiercely sought than has been the case in the past. Second, air traffic service organisations, which for a long time have been divisions within national service organisations, are being ‘privatised’ and urged to be run on a financially viable basis. These requirements sit very uncomfortably with the fact that the system is fundamentally capacity restricted. One argument can be that this is similar to what happens within surface transport systems, but there is a substantial difference that cannot be ignored. Aeroplanes, once they are airborne, are unable to slow, stop and sit with their engines shut off. Maintaining safety while also maintaining the demand for expeditious and orderly traffic conditions is a combination of well-recognised, but increasingly difficult, circumstances to balance.

1.5.4 Aircraft

The perfect aircraft would fly forever, consume no fuel, need no maintenance, its condition would never deteriorate and it would operate from a land area no bigger than its footprint, without creating any noise. The dream is impossible. Research engineers can devote boundless effort and energy to the pursuit of any of these objectives, and progress is often remarkable, but it is also faltering and slow. In recent times, the rate of progress has begun to reduce appreciably, and the commercial and technical risk implied by trying to engineer a 'breakthrough' is nowadays substantial.

Bankers, who underwrite the development bills, are unlikely to risk the amounts that will be needed to fund the kind of dream that drives and motivates much research. The airlines, simultaneously, want their say in the specification of vehicle properties as well. They want aircraft to be cheaper to operate and to be more versatile, in terms of the distances over which they can operate or the length of runways they can operate from, and so on. Within the remit of not becoming too great a risk-taker, there are fundamental dichotomies that the aircraft manufacturer cannot reconcile in some of these requirements, and these need to be fully understood by a wider audience if the aircraft is to remain an object of interest.

The modern airliner is being portrayed increasingly as a villainous creation, whose payload is invariably made up of people who cannot stem their greedy desires to travel unnecessarily and whose emissions and impact overall are environmentally unfriendly. The full capabilities offered by all stakeholders in the system will have to be used to devise individual contributions to the overall resolution of this unfortunate depiction of the future of air transport. Those within the relevant businesses must learn to live with critical appraisal and to accept the consequences of failure against any one count. They must also learn to balance their arguments, so that they can be awarded appropriate recognition for positive progress.

1.6 Future trends

Avenues for debate must be found to engender goodwill and offer encouragement and satisfaction. The increasingly strong temptation for some external sources of complaint is to bully the industry into submission, but this cannot be condoned as progress. To do so would restrict the entire industry and impose limits over what can be achieved in certain respects within society. Civil aviation has opened new opportunities for far too many people to be sidelined or abandoned on a whim. When it is able to serve universally within a remit that balances its pros and its cons objectively and sensibly, aviation will have succeeded in finding its feet. This is no time for people to be complacent within the industry. To stem development now

could be as disastrous to aviation as the consequences that would have flowed hundreds of years ago in the maritime business if the ship had been branded undesirable and nations still plied the seas in galleons today.

In the concluding sections, each element will be analysed in terms of how it is able best to cope with change. The possible outcomes of different scenarios will be investigated in general terms too, using a systemic approach wherever it is appropriate and providing some examples for those who have developed a taste for investigating the future through the new perspectives of systems analysis. There is never a guarantee that the best solution will be found, as the issues are complex and circumstances are forever changing. The application of processes that are justifiable in their own right and are also compatible with conventional thinking does, however, carry the promise of helping those trapped in one of the air transport system's elements to work out solutions that will be compatible around the whole system. That has to be regarded as good news.

2
The natural environment

Abstract: In this chapter interest is orientated around the Earth and its atmosphere. The structure of landmasses and oceans, the consequent distribution of human habitation and human habits are explored. Their relationships with the demand for air services, and many of the attributes of those services, are generally discussed. This introduces the concept of aviation being one of numerous modes of transport that often compete to fulfil demand. Also, and because aviation is the prime interest here, there is a brief study of the atmosphere, concentrating on the influence of aircraft properties and introducing qualities that are central to environmental fears.

Key words: the shape of demand, demand or traffic forecasting, international standard atmosphere, weather.

2.1 Introduction

Chapter 1 examined how demand between places within a group can be addressed, but left unanswered the question of what constitutes 'demand'. This is the very essence of all transportation issues. The call for a service to convey people is influenced by many factors. The principal attributes of demand need to be understood and allocated to the transport mode. In general, the 'propensity to travel' will be greater in higher-value economies, actual population clearly will have an influence and the modes of transport preferred will be influenced by availability, as well as the ability of individuals to afford certain modes. Almost all people can walk – provided the demand being analysed is not a sea journey – but beyond a certain distance they will express greater and greater desire for a more rapid mode of transport. After walking comes assisted human transport (bicycle, but could be skateboard or scooter), then public transport (bus or coach), motorbike/car, faster public transport (rail) and eventually air transport. In general, aviation is most suited to long-distance travel, but as time is as influential as distance, aircraft can be second to waterborne vehicles over

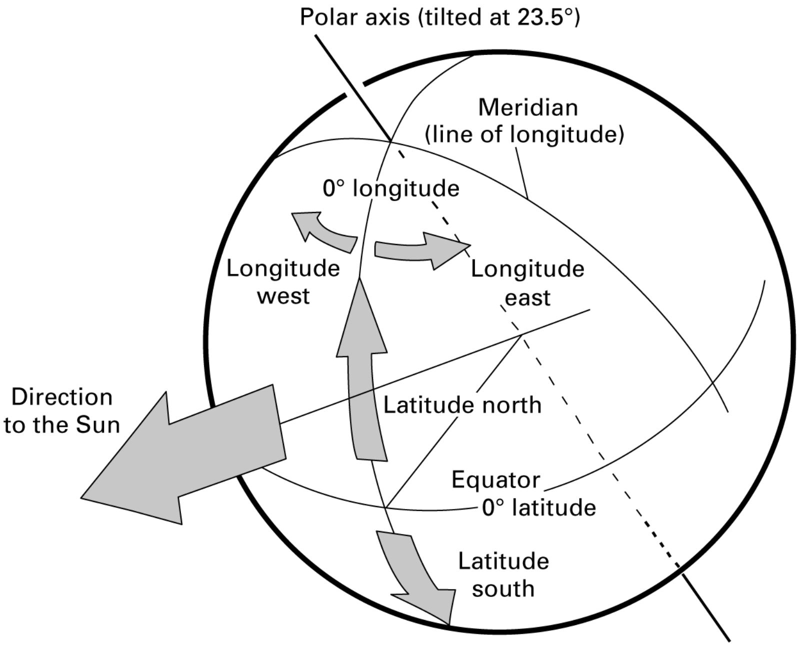
short stretches of water, and so on. In this section interest is expanded, encompassing aviation but not focusing on it. The structure of landmasses and oceans that makes up the surface of the Earth, the consequent distribution of human habitation and human habits become more important. Also, and because aviation is the prime interest here, there is a brief study of the atmosphere that embraces the planet.

2.2 The Earth as a habitat

The planet Earth is a sphere roughly 13 000 km in diameter and surrounded by a relatively thin gaseous layer, the atmosphere. The latter is comprised largely of nitrogen and oxygen (four-fifths and one-fifth respectively); it is the element in which aviation plies services between communities and it forms a fragile mantle on which life depends. It has been appreciated, increasingly, that the atmosphere has a close relationship with how flora and fauna develop and thus affects, through climate and physical contexts, the habitats in which we live. This view of the Earth as a fragile and illustratively beautiful inheritance that mankind must share with all other forms of life on the planet has been heightened by images brought from space. It is a dichotomy that aerospace technology has been able to heighten awareness, but at the same time the perspectives it can offer can invite interpretations that, unhindered, will be used to engineer its demise. Many managers will appreciate this is not an unusual circumstance, as such irreconcilable balances attract attention in many endeavours. At the present time the aviation industry is very vulnerable to attacks on its conduct, which can be regarded as contrary to human good. It has a part to play in ensuring human good, which will only be achievable if the whole business is seen to have common, noble and justifiable aims.

Staying with facts about the Earth, it orbits the Sun, completing one orbit each calendar year. This cycle affects many aspects of life and people's habits, and this in turn affects the demand for travel. Because the Earth's axis of rotation is inclined (at 23.5°) to the plane of the orbit, regions of the planet's surface receive solar radiation at different rates throughout the year. The year is defined into four phases, or seasons – spring, summer, autumn and winter – and the Earth rotates on its axis 365.25 times in a year, making 365 days (each arbitrarily subdivided into 24 hours) per calendar year, with 366 days every fourth (leap) year. The seasons are characterised by temperature variations, with 'summer' the hottest quarter of the year. The Earth's orbital inclination relative to the sun causes 'summer' to be in the middle of the calendar year in the northern hemisphere and at the changeover between calendar years in the southern hemisphere.

To define position on the Earth's surface, geographers use an angle-based grid system, as illustrated at Fig. 2.1. A meridian is a line that extends



2.1 Position reference on the Earth's surface.

between the two locations around which rotation takes place, which are the planet's natural poles (the North Pole and the South Pole). Any location on the Earth's surface will lie on a meridian, which is called a longitude. The reference meridian is the Greenwich Meridian, which passes due north–south through the district of Greenwich in East London, UK. Lines of longitude are defined as degrees east and west of the Greenwich Meridian; they meet at 180°, almost in the middle of the Pacific Ocean. Along most of its length this also serves as the International Data Line.

Perpendicular to the axis of rotation and cutting through the globe halfway between the North and South Poles is the Equator. Above and below this line, any position can be defined in terms of its angular displacement, and is expressed as latitude. The Equator is therefore 0° latitude and the North and South Poles are 90° north and 90° south respectively.

In the region within 23.5° of the Earth's equator the Sun is overhead at least twice during the year, which causes the seasons to be less obvious than at locations at higher latitudes. This band is called the tropics. In the tropics the ambient temperature is usually warm, rainfall can be plentiful, but sometimes seasonal (except in the centre of continental-sized landmasses), and snow is almost unknown (except at very high altitudes). Populations are plentiful and have typically sufficient food and resources to live equitably.

Thus, historically there has been some, but little, temptation to travel to find food, and so on, so different tropical regions tend to be culturally distinct and diverse, in terms of language, customs and in many cases religion.

At moderate, or so-called temperate, latitudes there is a distinct seasonal change throughout the year and associated climatic activity; with that have come different habits and different kinds of human populations. Largely these arise from temperature and rainfall changes and the way they affect humans in terms of their use of the land. Crops and people react in an annual pattern, induced by the warmer conditions of summer and the colder conditions of winter. There has been a greater temptation to migrate or to travel to conduct trade in these regions. Human movement patterns have caused the distinctions between cultures to reduce, although integration of this nature has not always been achieved peacefully. The desire to trade has caused some populations in these regions to develop resource surpluses, either through exploitation of natural elements – foods and materials – or by manufacturing. The demand for travel has therefore been greater in temperate regions than anywhere else on Earth, and economic prosperity, thus far in history at least, has evolved at a greater pace in temperate regions of the world.

Finally, at the most extreme latitudes are the polar regions. At these latitudes the Sun can be visible for a large proportion of the 24-hour day in the 'summer' and similarly the 'winter' can be largely dark. Snow and ice abounds, as temperatures are moderate to low. People are not numerous and their lives are hardy and relatively inclusive, with some limited trade between them and their neighbours.

The development of population and its ethnic habits, interesting as it is, has been alluded to in very general terms above, and it will not be delved into any more deeply. What is significant to the air transport researcher is that successive transportation developments, from travelling on the back of animals (horses and camels especially), through animal-drawn wagons and into the era of mechanically assisted travel, have cast aside some of the barriers between populations. The aeroplane has played a large part in the last 100 years or so, its speed and ease of use leading to accelerated rates of change in demand and a consequent expansion of travel habits between populations.

Even before air travel was available, the ease of travel throughout various world zones contributed to accelerated economic success in many populations. With economic prosperity came sanitation and medical care improvements that led to longer lives, and throughout the world there has been a massive human population explosion. From an aviation perspective, these circumstances initially saw growth in business demand, but now leisure travel has outgrown business demand. There is also a coincident rise in trade, and while much of the bulk cargo is best conveyed by surface means,

the speed of air travel has led to a boom in demand for the conveyance of perishable commodities and small high-value packages.

The telecommunication advances pioneered in the 20th century cannot be overlooked. They affect a population by introducing more news of places and events that stir the interest of people whose lives would not have been able to gather such information so readily in the past. There has been a long-held prognosis that with instant access to real-time news, telephone and video links, etc., populations would not need to travel to do business – they could do it 'on-line'. The converse effect seems to be true, with the greater appreciation of what is available elsewhere leading to populations wanting to see the world for themselves. It is having profound effects on the way that cultures evolve. There is little doubt that global air travel demand will continue to grow; the only uncertainty is whether progress will be smooth or hesitant, slow or fast, and to what extent the changes will be accommodated peacefully or with friction. It is estimated that while the world population grew from some 2.5 billion in 1950 to 6 billion in 2000, it will expand further, to around 9.25 billion, by 2050. It seems inevitable that the demand for air travel will soar rather than recede, which given its astonishing growth throughout the last half of the 20th century will pose some interesting problems.

2.3 The Earth: physical issues affecting demand

2.3.1 Surface

The planet's surface is the crust, and it is that part of the Earth on which all human activity takes place. The surface is divided into regions (tectonic plates) that move, infinitesimally slowly, across the Earth's surface, carried by the flow patterns in the magma beneath the crust. Where plates meet, the surface is ruptured and pushed upwards, creating mountains, and where they subdivide, which is usually in oceans, there are rifts, upon which volcanoes will form. There can also be volcanoes over regions where two plates meet, especially if one subducts beneath the other. These geological features define the shapes of continents and affect the fertility of land, and often accessibility, and thus govern how population is distributed over the Earth's landmasses. Intrinsically all the land that is populated is in the form of islands, either large or small.

Between the landmasses there is water. The level of the water varies diurnally, owing to gravitational effects creating tides, and can be referred to as the mean sea level (MSL). The accurate measurement of terrain height has resulted in maps that express height above mean sea level (AMSL) worldwide. Knowledge of the relative height of terrain is especially important in aviation, either with regard to being significant to operations

around airports or because in some parts of the world the landmass rises high enough to represent a significant en route hazard to aviation operations.

2.3.2 Core

The Earth comprises layers of material, the properties of which are manifold but which have only an occasional impact on aviation. Examples are volcanic ash, which can be a hazard to aviation because of its abrasive and suffocating nature, and earthquakes, which are hardly welcome anywhere. However, one particular property has been exploited by navigators for many centuries. The central part of the Earth comprises molten rock that has a high proportion of iron in its content, which is responsible for a strong magnetic field. The field emerged through 'magnetic poles' that are roughly coincident with the natural poles, and thus a magnetically sensitive needle will align itself to the direction of the magnetic poles. Across most of the Earth's surface it will be at a small angular displacement from the 'true' pole; this is a predictable error, called magnetic variation. This kind of field detector is the magnetic compass. Nautical navigators used the magnetic compass to guide the direction of travel between times when they could observe the sun or stars. Aircraft navigation initially inherited this discipline and the legacy where the magnetic compass, simple as it is, is still installed on all aircraft – large or small.

In recent decades very accurate measurement of terrain elevation has been achieved with satellite-based 'geodetic' measuring techniques. Nowadays the most accurate, and globally reconcilable, position references on the Earth (in terms of north/south, east/west or vertical positions) are those expressed as World Geodetic System (WGS) coordinates. The main reference used is WSG84. The way that the operational environment is reacting to these Earth-related technologies will be investigated later. For now a reminder has been posted regarding how human understanding of the world has gradually changed the way information is gathered, way-found and defined.

2.3.3 Continents

These are the largest landmasses and have been the cradles for distinct cultural divisions in humanity. Over preceding centuries travel between these regions has risen from a trickle, through recorded periods of exploration, to the time when sea-going vessels have been able to convey significant numbers of people, initially one way, thus adding momentum to migratory patterns, and merchant ships have been able to carry goods for international trade. When the aeroplane appeared it brought the time taken to travel anywhere in the world down to an insignificant proportion of a

lifetime, and led to an explosion in the demand for travel. If a 24-hour time horizon is indicative of what marks the limit for mass migration, the aeroplane has opened the world to all people.

People have always wanted to travel, to engage in trade, for territorial wants or through sheer curiosity. In some continents mountainous landmass regions have deterred surface travel. Likewise, certain regions of the seas can be so tempestuous that even short sea journeys can be hazardous. These are examples of physical characteristics that have contributed to the distribution of population and to the shape of the demand for travel between them.

While aviation has offered wider access between communities over the last century, the majority of the world's population has still not yet flown. Only a small fraction of the population flies habitually and regularly. Nevertheless, the demand for air travel has grown rapidly, the first significant levels of commercial operations commencing only in the 1930s. All the indices that can be used to predict demand suggest that there will continue to be growth in air transport demand for many decades into the future, and the rate at which it will rise will equal or exceed growth rates already recorded. The industry needs to have a good idea of what is likely to be in store, so developing ways to forecast demand is essential.

2.4 The shape of demand

Knowing what 'demand' (passengers per unit of time) there is for a service at the present time is essential to planning the introduction of a transportation service. The desire is to provide a service that will continue to serve demand. Thus some idea is desirable as to how service demand will evolve over time. This is traffic forecasting.

Traffic forecasters tend to divide the world's population into entities and to assess what propensity there is to travel between various clusters of people. One way to do this is to subdivide them as national populations, within some 200 countries. However, countries are territories on the Earth's surface (defined by physical features or specific references, mainly on the landmasses) governed by their own rules, so sometimes this is too coarse a way to examine the diversity of the population. Most large nations have their own language and some nations share a common language, but in some cases, such as when a 'nation' comprises a scattering of islands, there can be many languages in one realm. Then, within a country, the population is not evenly distributed. It can be sparsely spread throughout rural areas or congregated in cities. In most nations there is one city that is the administrative, legislative and governmental hub (although these functions are divided in some countries), which is referred to as the capital city. It is usual for the capital city to have the busiest airport (or set of airports) in the nation. Other cities or regions may have their own airports.

Throughout the world there are some 2000 airports with daily scheduled services that radiate from them – and the number grows annually. Great areas, such as China, are just beginning to expand their economic capability and are investing in airports at a rate that equals the rate at which they opened in North America in its most expansive period. Worldwide there are also small airports that are beginning to attract people to use them, to sample convenience of access or to sample a new genre of air travel experience, and thus, by 2050, the actual number of airports that will host scheduled services might be considerably more. Already some 30 000 airfields and strips exist worldwide, albeit the majority of these are used by general and business aviation, whose activities are distinct from those of airlines.

Airlines only operate between locations where there is sufficient demand for their services to be warranted – be that for passengers or freight. Therefore, if there is a steady demand they will offer a scheduled service, perhaps daily or even several times daily, if demand is very high. Ad hoc demand can be catered for through charters, where the aircraft will arrive to operate a service when there is adequate demand only. Where there is a specific demand, such as for holiday travel, the service might be provided seasonally, and the operator of a regular timetable who sells seats through holiday companies will be a scheduled carrier, but may be a so-called inclusive-tour (I/T) operator.

2.5 Demand forecasting

Airlines assess the possibility of a new route and airports look into the possibilities of what they should promote as new routes by conducting traffic forecast studies. Traffic forecasting attempts to predict the demand on routes, usually by looking at current situations that affect demand and by considering their probable evolution over the period of time of interest to them. The methodologies in use vary depending on the circumstances and the data available. Traffic forecasting is fundamental to establishing the scale and scope of all operations considered in later chapters. Nowadays, forecasting can be conducted globally (looking at the demand between nations) or specifically (looking at the demand between points). Both kinds of forecasting will be implied in the review of forecasting methods that follows.

2.5.1 Historical demand forecasting

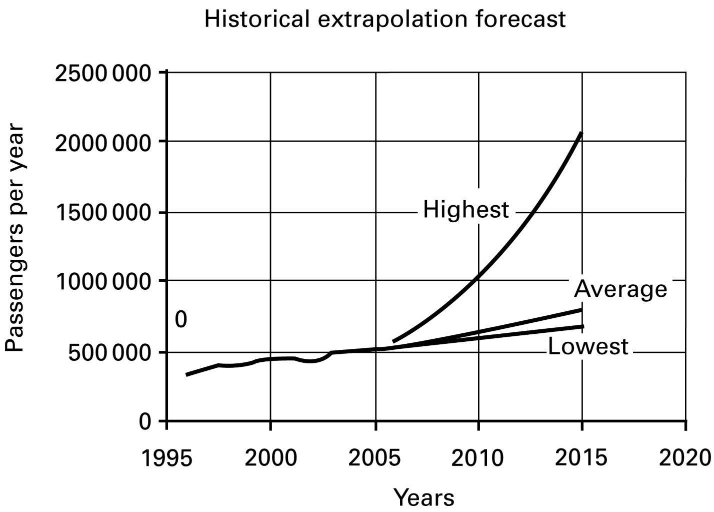
If there are historical data from previous years these may be a practical measurement that can be adapted to forecast a predicted demand. This is the least risky way of predicting demand, but it is not so straightforward as might be imagined.

Plotting such data as points, with demand (passengers per unit of time) on the vertical axis and years across the horizontal axis, will invariably reveal that the data points are ‘scattered’. Real-life data are influenced by so many events and factors that it would be unreasonable ever to expect the data to sit on an obvious line. While it is easy to draw a straight line by eye, different people will draw different lines.

The mathematical solution is to use a process of ‘best fit’. This is readily done using modern spreadsheet programs, which will also furnish a measure of the correlation coefficient or one of many other ‘goodness of fit’ expressions. This is the simplest possible forecast, but there are many good reasons for believing that it is the wrong geometric fit to assume.

For example, a steady percentage annual growth rate, which might be a realistic expectation, will translate into a curve that becomes increasingly steep over time. There may be market conditions that will mitigate against continuous growth – all travel markets tend to ‘saturate’ at some time – so this is an assumption that cannot always be depended upon (see Fig. 2.2).

The discussion shows that the extrapolation of a traffic sample is a risky choice for the mathematical observer of data. It is inevitable that the further into the future the observer probes, the less certainty there will be in the quality of the results obtained. Clearly, having historical data is better than having nothing, but it is hardly ever a totally reliably guide to what will happen on individual airline routes.



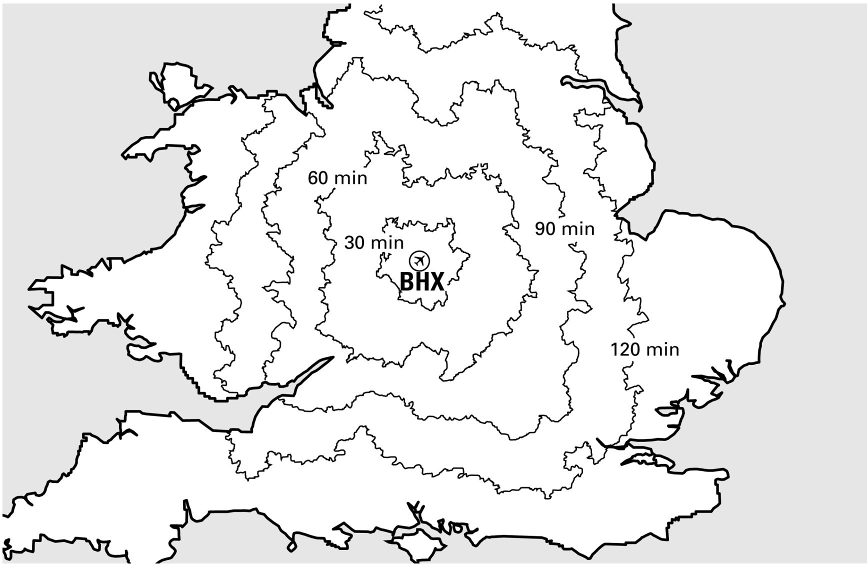
2.2 Example of a historical traffic extrapolation.

2.5.2 Comparative analysis

If a situation with no historical data is being studied, information regarding similar circumstances – between airports at similar distances and with similar local population interests, for example – can be adapted. Imagine that the demands on services from a well-established airport to three particular destinations are known. The simplest deduction to make is that the ratio of demand to all three airports from another airport in the same country might be expected to relate to these services. That relationship could be in terms of the same ranking, and perhaps in similar proportions. Whether it would be a small or significant proportion of the existing demand is only determined by having knowledge of several additional issues. These are 'community of interest factors' and can include such aspects as:

- the ground-based infrastructure that serves each of the airports
- local geographic features
- the distribution of the population, in social and cultural categories, throughout the region around the airports.

Airport catchment areas are the regions from where demand is drawn. They can be illustrated as isochrome charts (see Fig. 2.3), diagrams where lines of equivalent time to access are drawn. Inevitably, the catchment areas of neighbouring airports can overlap, meaning that the airports will compete: strongly in regions where the access criteria are similar, but less so as one gets closer to one or other of the airports. A very decisive factor is the



2.3 An airport isochrome diagram (Source: Birmingham Airport).

existing volume of services. A large international airport will dominate over a small regional service airport when all other factors in the catchment assessment equations are equal, for example.

Statistical methods can be used to factor the propensity to use a particular airport, but in every case there are difficulties because the number of influences is very high. Therefore, relating them by using factors in equations is often difficult to justify.

Comparative data are therefore a valuable source of comfort for a forecaster. The data can help to predict, if not exactly what will happen, what possibilities are likely to be evident in the future. The astute user is asked to take note of trends and to be prepared to expect comparative data-based forecasts to offer credible, but not always predictable, scenarios.

2.5.3 Theoretical demand models

When there is no clear precedent on which to base traffic estimates, in effect the forecaster has a clean sheet of paper and the only option left is to use a theoretical process. The many techniques that can be used often will adapt from historical or comparative studies, perhaps in related traffic fields; any form of surface travel that links the same regions can be a first-order indicator of the circumstances that pertain and will influence the characteristics of a theoretical forecast. These notes will concentrate on one technique, which is the most widely used but not the universal choice of forecasters. This is the so-called 'gravity model'.

The idea of treating populations as units with attractiveness for one another, akin to gravitational pull, was first proposed as long ago as the mid-19th century. A gravity model equation predicts the scale of demand between two locations by assuming there is attractiveness which is proportional to:

- the population at each location, such that as population increases so does demand
- the distance between them, such that as distance increases demand decreases.

The formula can be factored in many ways. In the simplest case, where population is assumed to be a linear relationship and range is an inverse square (as in gravity equations in physics), the demand between two towns with populations P_1 and P_2 and distance r apart would be given by

$$\text{Passenger demand} = k\ \frac{P_1\ P_2}{r^2}$$

where

P_1 and P_2 are the populations at locations 1 and 2 respectively
r is the distance between them
k is a factor that reconciles units

This yields a result that shows that two similar-sized towns generate greater demand if they are closer together. This is true for *all* transport modes, so a gravity model result has to be factored to extract the air transport proportion. The travel demand between two adjacent housing estates will perhaps be considerable, but the proportion of people that would use an aircraft to make the journey can be regarded as nil. Two similar patches of population a few miles apart in almost any country will still generate very little, and justifiably assumed to be nil, air transport demand. If the short distance is flat agricultural land, the answer is almost certain to be nil, but if the area is a treacherous patch of water, the aeroplane could be the most convenient, even safest, mode of all possible transport options. The judgement that must be applied to make a justifiable modal-split across all possible transport modes should not be guesswork, and this is where comparative or historical data are often used to 'calibrate' the assumptions that are incorporated.

Experience has shown that an analogous gravity model equation, with an r^2 term, for example, does not correlate with real-life data. The exponent value (2 in the analogous version) tends to be a lower value when assessing demand between destinations that have other transport mode competitors, but can approach 2, or be even higher, between destinations with little transport mode competition. Islands have different demand characteristics that can affect the best value to use.

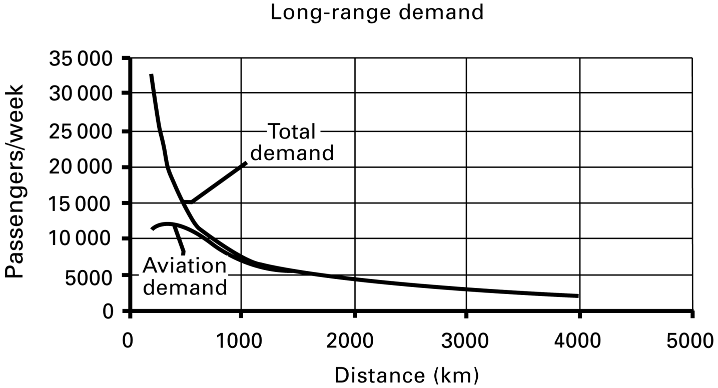
Even more significantly, population attributes such as density, social and cultural categories have to be taken into account. This is usually accommodated by multiplying the basic demand equation by factors.

Finally, as busy airports tend to be more successful at attracting passengers than less busy airports, gravity model applications are often more reliable if they use existing traffic levels, not population. Thus the simple equation becomes

$$\text{Passenger demand} = \frac{f(K_1,\ K_2,\ \ldots, K_x)(T_1 T_2)}{r^n}$$

where

K_1 to K_x are factors that represent relevant population attributes
T_1, T_2 are the traffic levels at the two airports of interest
n is an exponent that usually relates to geographical circumstances
r is the distance between them



2.4 Example of gravity model forecast characteristics.

If traffic level is used, then a gravity model based assessment of demand is almost impossible for a new airport. A mixture of historical data, reading across from equivalent situations, plus gravity modelling (see Fig. 2.4) is the best approach.

The assumptions that relate to population attributes are, in many respects, also related to fare structure. Increasingly, therefore, as more complex fare structures have emerged, gravity forecasts have also had to be subdivided into categories that reflect the journey purpose and to assume their bias towards specific fare structures. For example, the behaviour of business and leisure travellers affects demand considerably, and a modelling technique that takes into account seasonal variations is also used when detailed forecasting is conducted.

At this stage the basis on which forecasts are developed has been described. The significance of the details referred to above and the uncertainties that surround long-term forecasts re-emerge as the objectives steering strategic decision-making in businesses and are considered later.

It is important to appreciate that all forecasts are based on data drawn and decisions taken at a particular point in time and therefore they become stale and need to be revisited at frequent intervals. Adjustments can address changes that have occurred in demography, local developments (for example new surface infrastructure) or in society overall. If town populations are expanding or diminishing, the rate of change needs to be determined and any shift in the distribution of wealth needs to be assessed and quantified.

2.6 The reliability of forecasts

Forecasting is a modelling process that attempts to describe the habits of people and requires judgement concerning the relationship between

variables that might seem to have little statistical correlation. A good forecaster is one who has a reputation for making good predictions, and the common wisdom is that consistently good results indicate there is a sharp mind behind the analytical processes on which the forecasts are built. This is true, without doubt, but the goodness comes as much from intuition as it does from analytical processes.

Forecasting will not get easier as more historical or comparative data are accumulated. Aviation has greatly affected the way that communities have responded to travel opportunities, largely through providing access to more distant locations with greater ease and at reasonable cost. Business-related connections have grown rapidly, with aviation offering almost instant face-to-face access to any community worldwide, but will the development of more accessible real-time telecommunication links begin to impact the rate of growth? The patterns of migration of the old, driven by disease or war, have been swamped by the opportunities that have opened up in the last few decades, with access to places attributed with better standards of living. The opportunity for people to keep in touch, and even to move back to their original domicile if they so wish, is greater than ever. The first generation of leisure destinations – almost exclusively within nations – was established barely 200 years ago, but these locations have seen their exclusivity diminished as new leisure destinations, tailored to meet demand that was hitherto unimaginable, have emerged well beyond national borders.

In turn, these socioeconomic developments have opened new legislative issues, in terms of who profits from the services that link communities, who has access to what nations, where and when, and so on. Furthermore, political influences cannot be ignored and are not as constant as might be imagined. The legislative processes that need to be understood in order to integrate consideration of these issues are addressed in the next chapter.

2.7 The Earth: atmosphere

Finally, because its influence will appear regularly, it is appropriate to explore general characteristics of the Earth's atmosphere. Aircraft need air on two accounts. First, to generate the force that keeps them aloft and, second, to provide oxygen that is burned with fuel to liberate energy. Air vehicles, because they do not have contact with the surface of the Earth, face less physical impediment than any vehicles that travel on the surface. They should need less energy to propel them at a given speed and thus should be among the most economical forms of travel. People yearn for speed, especially for long-haul travel, and the design of airliners has concentrated on relatively high speeds, when compared with surface-based competitors.

Table 2.1 ISA parameters at different altitudes

Altitude (ft)	Temperature (kelvin)	Pressure (millibars)	Density (kg/m^3)	Speed of sound (knots)
0	288	1013.2	1.228	660.39
10 000	268.18	696.60	0.9042	637.26
20 000	248.37	465.32	0.6522	613.26
30 000	228.55	300.57	0.4578	588.29
36 000	216.66	226.98	0.3647	572.78
40 000	216.5	187.26	0.3011	572.57
50 000	216.5	115.57	0.1886	572.57

2.7.1 Gaseous properties

The qualities of a gaseous substance such as air can be expressed in terms of temperature, pressure and density. These are the three leading properties of all gases. Because pressure waves that propagate through air are registered as sound and the speed of sound has a significant bearing on the performance of aircraft, this is also a property of the atmosphere that is of interest.

A 'mean' atmosphere, the so-called international standard atmosphere (ISA), is based on the premise that there is a constant temperature lapse rate (6.5 K/1000 m) from sea level (temperature = 15°C, or 288 K) to the tropopause at 11 000 m (36 089 ft). At this altitude and higher (which is in the stratosphere), the temperature is constant at −56.5°C (216.5 K).

Table 2.1 shows that air is not weightless – the density at sea level (in ISA) is a considerable 1.228 kg/m^3. It also shows that the speed of sound decreases from sea level up to 11 000 m (36 089 ft) and at higher altitudes it is constant. For the purposes of this text ISA can be assumed to be a reference atmospheric condition applicable worldwide, but in fact the atmosphere is deeper in tropical regions than it is in polar regions. The region up to 11 000 m altitude is called the troposphere, above this – in the regions used by commercial aircraft – is the stratosphere and the 11 000 m (36 089 ft) altitude is called the tropopause.

Jet-powered commercial airliners prefer to cruise in the regions close to the tropopause, while turboprop-powered airliners cruise at lower altitudes – perhaps down to 18 000 ft on short-range operations.

2.7.2 Distance and speed

Note that a speed expressed in knots is the same as stating the speed in nautical miles per hour. The nautical mile (naut. mile) is defined as 1 minute of arc on a line of longitude, so 1 degree of latitude (or 1 degree of longitude

Table 2.2 Useful distance and speed unit conversion factors

Distances		
1 nautical mile is	1854 metres	(6080 ft)
1 statute mile is	1610 metres	(5280 ft)
1 kilometre is	1000 metres	(3280 ft)
Speed		
1 nautical mile per hour is	1 knot	
1 mile per hour (mph) is	1.152 knots	
1 kilometre per hour (km/h) is	1.854 knots	

at the Equator only) is 60 nautical miles. The Earth's equatorial circumference is thus $60 \times 360 = 21\,600$ naut. miles.

Most land-based distances are expressed in kilometres, or statute miles, so it is necessary to understand the relationships between the different ways of expressing distance and speed. A comparison of the units used traditionally and those used throughout aviation is shown in Table 2.2.

A further way of expressing speed information is by referring to the local speed of sound. Expressing the speed of an aircraft as a proportion of the speed of sound is referred to as the *Mach number*. Hence flying at 458 knots at 45 000 ft, where the local speed of sound is 573 knots, the Mach number is $(458/573) = 0.80$. This is referred to as Mach 0.8 and is often written as $M = 0.80$.

2.7.3 Within the atmosphere: weather

The atmosphere is not quiescent and the changes that take place within it give rise to what can be grouped as 'weather'. The main contributor to these changes is the daily temperature variations across day and night. The effect at any particular point on the Earth's surface is influenced also by the local terrain (shape, absorption and/or reflectivity), water moisture content (humidity) and, clearly, sunrise and sunset times. These are the major aspects only as a meteorological model will track many other properties of the atmosphere. Most 'weather' forms within the troposphere, although there are some extreme weather conditions that do reach into the stratosphere.

Weather 'systems' arise from pressure differences across regions, and cause air to swirl, either clockwise or anticlockwise. A 'high-pressure' region (clockwise rotating in the Northern Hemisphere) is called a cyclonic system and a 'low-pressure' region (anticlockwise rotating in the Northern Hemisphere) is called a depression. (These systems rotate in the opposite direction in the Southern Hemisphere.) The terms 'high' and 'low' refer to the pressure at the centre of the system, relative to normal atmospheric pressure, which is 1013.2 millibars according to the definitions used in ISA.

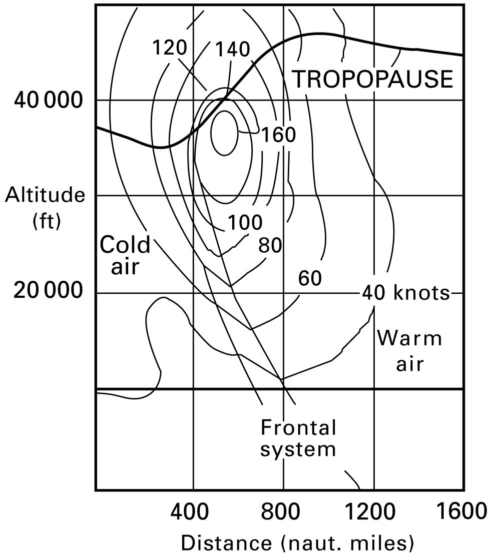
Lines of constant pressure in the atmosphere (isobars) show where these are within a weather system and are presented on weather charts. Closely packed isobars show where the air movement is greatest – and in physical terms this means windiest. Winds spiral towards the centre of low-pressure regions (trying to fill them) and from the centre of high-pressure regions (trying to empty them).

This is a very simple view, and the Earth's rotation effects and the efficiency of processes of water absorption need to be studied as well, to gather full knowledge of the energy-driven mechanics of the atmosphere. On the whole, a high-pressure region is fairly cloudless and is the basis of hot settled periods in summer (and even prolonged frost in winter), whereas a low-pressure region is often where moist air is drawn in. Thus clouds form and, in extremis, tropical storms of hurricane intensity evolve.

Where airflows meet, the air masses create 'fronts'. These are where significant cloud masses form. Other cloud formation mechanisms exist, but at fronts severe weather can often emerge from what has seemed a benign surrounding region. Clouds can form at different altitudes and take a variety of shapes and names. Large cloud masses tend to form over water and to be swept over land, but clouds can also form when air rises over mountains or even when it is over fields. They can also occur in a special form 'downwind' of mountains. Moisture will form cloud even in still air simply because, as the temperature falls, if the air can no longer carry the water vapour as 'humidity' it must condense into a cloud. In this case it creates a 'mist', and when it happens at the Earth's surface it is 'fog'. This is the most lethal and dangerous of all weather phenomena commonly encountered by aviators.

Among weather effects of interest generally to aviation is the tendency in some temperate latitudes for the interactions of hot/cold masses at the tropopause to create zones of high winds, which are concentrated and are called 'jetstreams' (see Fig. 2.5). These occur at high latitudes and tend to flow according to regular patterns, so they can be forecast and are useful if an aircraft can fly in them. They literally carry the aircraft along in the flow. In some circumstances – but not on all occasions - the air around this fast-flowing core can be very turbulent, but no cloud will form. This is one form of a phenomenon called 'clear-air turbulence' (CAT). It can also form along weather fronts and might persist for long distances, giving a gentle but continuous shaking of the aircraft. It is sometimes referred to as 'cobblestone' turbulence, and although not dangerous it upsets passengers and is best avoided by choosing to fly above it. Climbing only 1000 ft or so can take the aircraft into smooth air. CAT is difficult to forecast and can be dangerous. This is the main reason for passengers being urged to keep their seat belts fastened, but not necessarily tightly, throughout a flight.

Within the fast-flowing 'jetstream' the core is smooth and will give an air



2.5 Cross-section of a jetstream.

vehicle a free ride at a speed typically over 100 knots, occasionally up to 200 knots and on rare occasions even faster. Jetstreams always flow from west to east, and because aircraft fly at a speed relative to the air mass they are immersed in, a 480-knot true airspeed can become a 600–680-knot ground speed in these circumstances. Even subsonic airliners can thus attain an almost ‘supersonic’ block speed, and have been known to fly from North America to Europe as much as two hours faster than their allocated time. Conversely, they face the prospect of large headwinds on the way back, but meteorological services work out how they can thread best through the circulating air masses and will minimise the headwind effects that crews have to face on a westbound journey. These kinds of weather effects will cause an airline timetable to show a marked difference between eastbound and westbound flight times on any given long-range east–west route.

In extreme weather conditions, especially when vertical air movements cause moist air to rise rapidly, the air mass will be cooled suddenly. This creates ice particles that will start as snow flakes and can conglomerate to form hailstones. When the ice stays in a ‘super-cooled’ condition (as often does happen in clouds) ice will precipitate readily on to the wing of any passing airliner. Ice can accumulate rapidly, both weighing an aircraft down and simultaneously destroying the aerodynamic properties that will assure it safe passage through the air. Because it is such a serious issue, aircraft have ice detectors and ice protection systems that the crew use as soon as ice is detected. In some weather systems, icing conditions can occur unexpectedly

and cause ice to build up so rapidly that occasionally a crew will fly with the system permanently switched on. This does not improve fuel efficiency, but it is a vital safety precaution.

2.7.4 Weather effects on navigation

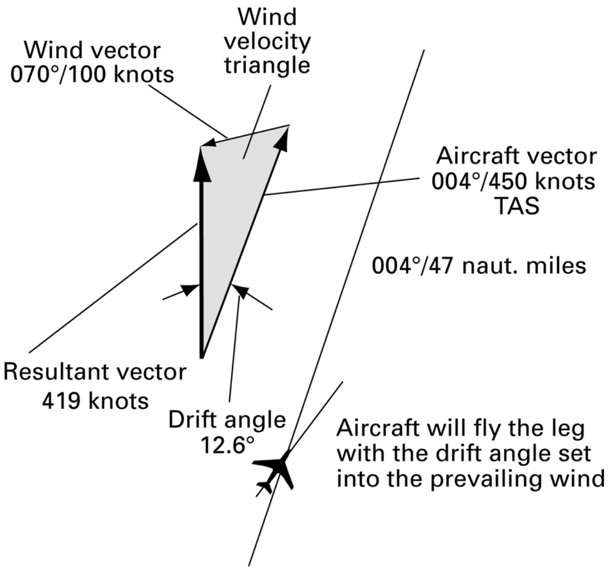
Weather effects determine how aircraft are navigated. The wind velocity triangle, so called because it can be visualised as a triangle of vector quantities (in mathematics this means that the quantity has length and direction), allows visualisation of the direction of flight (the track) that an aircraft will make good while it is pointed in a different direction (the heading). It is similar to the way that tidal flows can cause a ship to head in one direction and to track in another.

Take an example. If an aircraft flies directly north and the wind is either from the north or the south, it will generate a headwind or a tailwind, respectively impeding or carrying the aircraft along its track. In this case the aircraft is heading due north and maintains a northerly track. A wind is expressed in terms of direction and speed, and a wind from the north at 20 knots is referred to as 000°/20 knots. A similar strength wind from the south is referred to as 180°/20 knots. The wind heading uses the 360° reference used in geometry and the direction of the wind is where it comes *from*.

If there is a wind from the west, it is said to be from 270°. If the wind is light (in strength or slow-moving) it will not greatly affect the aircraft, but as wind speed increases, because the aircraft will be carried within the air mass, it will cause the aircraft to move sideways as it also moves forward, which causes the speed across the ground to change and the direction of travel to be different from the direction in which the aircraft is pointing. Wind direction is always referred to according to the magnetic reference. (This is because the convention is to use a process that will be universal across all aircraft in a region of airspace, and the smallest and least sophisticated aircraft have only magnetic compass directional indicators.)

The way to solve the navigation situation on paper is to construct the wind velocity triangle. Thus (see Fig. 2.6):

- Draw the aircraft speed vector (a line with a length proportional to its true airspeed, in the direction the aircraft is pointing on the magnetic compass – this is the aircraft *heading*). It is suggested that the vector is drawn with an arrowhead showing the direction of flight.
- At the arrowhead end of the above line construct the wind vector (a line whose length is proportional to the wind speed, and pointing along the direction in which the wind is blowing). The wind vector arrow points away from the aircraft vector, so draw an arrowhead on that too. It is easier to do than to describe!



2.6 A wind velocity triangle.

- Finally, draw a line that links the two ends of these 'vectors', thus forming a triangle. (This is sometimes referred to as the 'resultant' vector.) This line can also have an arrow placed at one end and the vector should start from where the aircraft vector started, and have the arrow at the end where the wind vector arrow is located.

The resultant vector provides two vital pieces of information. First, the length of the line will be proportional to the aircraft's speed across the ground, or its groundspeed. The angle between the resultant and aircraft vectors is called the *drift angle*. If the aircraft is pointed on the heading desired, it will be blown off course by this angle. The aircrew thus have to set a correction on the heading, proportional to the drift angle (angling the aircraft into the wind), to maintain the *track* that is desired across the ground.

The above is so fundamental to navigation that it is necessary for all pilots, whether they are in a small, light aircraft or the greatest and fastest of airliners, or even a military jet, to understand the principles of the wind velocity triangle. When aircraft systems are considered it will become clear that on modern aircraft there are computers that can conduct the calculations for a crew. Experience has shown that the crew must take steps to remain aware of the fundamental principles involved, however, as to lose 'situational awareness' is one of the most critical parts of all safety aspects of flying. This is a situation that comes to haunt some aspects

considered later in the chapters of this book, when automation is considered and espoused.

Having found out what natural issues circumscribe what can be achieved in aviation, it is time to turn towards the regulatory environment, where mechanisms that are man-made can impede or encourage air travel, and are plentiful.

3
The regulatory environment

Abstract: This chapter reviews how each nation, although it has its own desires and interests, is obliged to enact international air law. The content and structure of air service treaties, or agreements with other nations, are examined. It is shown that air transport businesses rely increasingly on globally compatible systems, regulated through statutory instruments and administered by international bodies. Changes that mark 'liberal' regulation are introduced and exemplified with descriptions of 'deregulation', in service agreements and the quest for 'best practice' in technical regulation. These are examples of how regulators attempt to exploit the benefits and to avoid the pitfalls of the latest technological developments.

Key words: ICAO; Annexes of the Chicago Convention, IATA, freedoms of the air, deregulation, privatisation, safety regulation, risk assessment, human factors.

3.1 Introduction

Each nation has its own desires and interests as a society and the principles it chooses to uphold are trusted to its own government. With regard to aviation, a government is obliged to enact international air law, pertaining to operations and safety, and with regard to commercial and political interests will negotiate air service treaties or agreements with other nations (or, in rare cases, may shun any agreements at all and therefore be an isolated state). The fact that there are many forms of government should not prevent the attainment of reliable and consistent safety standards internationally. This has been well understood and practised, with some allowances for local distinctions, throughout aviation history.

However, as the air transport business relies increasingly on globally compatible systems, in respect of both commercial and technical endeavours, pressure mounts to achieve extremely onerous levels of commonality. The challenges in drafting still individually tailored but increasingly compatible statutes are as great today as ever before. The regulatory

environment will continue to change in the years to come, as the areas into which statutory requirements reach will almost certainly increase. Liberal regulators have already begun to show that they can look for areas where their influence may be diminished, but they ask for the need to be recognised to embrace new ideals, especially to exploit the benefits and to avoid the pitfalls of the latest technological developments.

3.2 The breadth of regulation

There are two major aspects to regulation – economic and technical. They are administered separately in most countries and there is a major international coordination body in each sphere, these being the International Civil Aviation Organisation (ICAO) looking after safety-orientated regulation and the International Air Transport Association (IATA) looking after commercially sensitive regulation.

The structure and function of each will be examined separately, but as their separate responsibilities are shared over a broad common boundary, the degree to which individual nations are free to negotiate their own terms of reference for legislation, especially nation-to-nation, need to be considered. Most combinations of nations have negotiated and ratified 'bilateral traffic agreements'. These are reviewed periodically, and overall the rules that emerge from such negotiations will set limits on points of access, capacity on services and the actual designation of air service suppliers. The negotiations have to respect the influence of 'freedoms of the air', which are vested in ICAO and detailed later, and the competitiveness of nations in seeking to manage market share, through the use of computerised reservation systems (CRS) and such mechanisms as code-sharing, which are topics vested within IATA. Both organisations will monitor such developments and in many cases, through their regular involvement and oversight, they can assist in the drafting of such agreements, thus saving time and money.

Where 'deregulation' is being approved, national authorities are given freedom to dismantle components of their own regulatory organisation and procedures, where they so wish. However, an overriding provision is that the less bureaucratic legislative processes that emerge must still be compatible with the requirements of the international community. The clearest example of this has been the dismantling of route-licensing procedures, whereby an airline had to seek approval to compete on a route with an incumbent operator. While allowed in principle, this is not allowed to proceed without some restraint, for example in terms of respecting capacity constraints at airports, which might be administered by the IATA through its Scheduling Services division.

Similar issues are arising more frequently nowadays as 'privatisation' of

publicly owned entities – the airport and airspace service provision in many countries – gathers pace. ICAO and IATA are still the organisations to which the national authorities have to defer many obligations that will impinge on international operations. It is no good, to consider an extreme case, if a nation uses a unique navigation system, as this will impose an operating cost disadvantage on airlines that use that nation's airspace over those of its competitors who do not visit that nation.

Deregulation and privatisation are topics that will arise as the themes in later chapters are examined in greater detail. Their introduction here is to provide a reminder that these are not the almost maverick actions that popular press coverage will sometimes describe.

3.2.1 International Civil Aviation Organisation (ICAO)

The International Civil Aviation Organisation (ICAO) is the supreme legislative body overseeing technical-based aspects of international air transport operations. ICAO takes responsibility for the framework against which much of the international air law pertaining to operations and safety worldwide is drafted.

Its responsibilities date from 1944, when it was founded, but many of the principles it adheres to can be found in legislation that pre-dates this period. It was in Europe, where nations were cheek by jowl and air travel was beginning to take hold, that the first international air agreements were drafted and enacted, from as early as 1919. Once in place, regulations have to live and breathe. They are under perpetual review, with experts tracking every issue, almost day-by-day, and urging the re-drafting of time-expired or hole-riddled statutes. As international laws are debated at length before being enacted, they can seem to be part of a process that, to those driven by entrepreneurial flair, is apparently staid, slow and counter-productive. Thus far, ICAO has walked the tightrope between being overzealous and too relaxed very successfully. Given the tribulations on which it has often to be arbitrator, this is a statement made with considerable respect.

ICAO is headquartered in Montreal, Canada, and has regional offices worldwide. All United Nation (UN) States are eligible members, and at the current time that makes over 200. Representatives from all contracting nations (there are few exceptions from the UN membership) form the ICAO Assembly, which meets three-yearly, reviews working and sets future policy. At the same meeting a three-yearly budget is also set.

The Assembly is assisted in its more regular duties by a Council, which comprises members from 36 States. The composition of the Council is readdressed at each three-yearly Assembly meeting. As a part of its routine procedures the Council ratifies ICAO Standards and Recommended Practices (SARPs), which are the basis of its most important legislative

Table 3.1 Annexes of the ICAO Chicago Convention

Annex	Subject
1	Personnel licensing
2	Rules of the air
3	Meteorological services for international air navigation
4	Aeronautical charts
5	Units of measurement to be used in air and on ground operations
6	Operation of aircraft
7	Aircraft nationality and registration marks
8	Airworthiness of aircraft
9	Facilitation
10	Aeronautical telecommunications
11	Air traffic services
12	Search and rescue
13	Aircraft accident and incident investigation
14	Aerodromes
15	Aeronautical information services
16	Environmental protection
17	Security
18	The safe transport of dangerous goods by air

output, the ICAO Annexes. These are so named because the first SARPs were written and published as Annexes to the ICAO inaugural Chicago Convention. These fundamental statutes remain in that format, expanded from the 15 produced after 1944 to 18 in current usage. The complete list is given in Table 3.1. The procedures engendered by these Annexes assure commonality, in terms of equipment and procedures, accepted levels of safety, and so on.

Specific duties with regard to ensuring the SARPs are up-to-date and technically proactive are vested in several ICAO Bureaux. These include the Air Navigation Bureau, which develops technical studies relating to the safety, regularity and efficiency of international air navigation. It has had a very significant role to play over the last two decades or so, in ensuring that debate worldwide has led to acceptable international air navigation standards that will allow an expansion in the capability of airspace service provision. Without this development the benefits of new systems that will ensure efficient use of air vehicles and airspace would have been almost certainly lost. The committee that has handled this work is the Future Air Navigation Systems (FANS) Committee, and its responsibilities and achievements in terms of defining the attribute of global communication navigation and surveillance and air traffic management (CNS/ATM) processes will become increasingly apparent in later chapters.

The Air Transport Bureau within ICAO is the division within which there is perhaps the greatest overlap with IATA. They consider unlawful

interference (terrorism and security threats) in particular, and especially they have influenced the extension of the Annexes over the years. Alongside the major technical bureaux is the Legal Committee and such specialist units as those that administer the Technical Co-operation Programme. Without a source of support from what is the centre of activity in respect of future developments, the majority of nations – whose interest in new systems is not associated with their technical development – would be left with the impression that the organisation was intent only on giving support and encouragement to the richer nations.

Finally, ICAO is the source of a vital set of agreements that are principally commercial. These are the 'freedoms of the air', which were first expressed in the 1944 Chicago Convention. They have been extended since and are so fundamental to the way that bilateral agreements, and more recenting 'de-regulation' developments, are scoped that they are presented in more detail later in this chapter.

3.2.2 International Air Transport Association (IATA)

The International Air Transport Association (IATA) was created almost at the same time as ICAO, and also with worldwide reach and also headquartered in Montreal. However, this is not an organisation that sets rules for governments. It is a less kindred association of representatives from privately and publicly owned aircraft operators. Those organisations that are members have chosen to join it, and the 230 airline members as of 2008 (of some thousand airlines worldwide) were responsible for 95% of the total passenger-kilometres performed each year.

IATA produce considerable quantities of statistical data concentrated on routes and financial and other business information. These data tend to be derived from member company records, as the membership is almost wholly scheduled carriers. They are a useful source for forecasters, but IATA does withhold commercially sensitive information from the public.

IATA can pick up current technical affairs, but these tend to be ICAO's responsibility, and they only take issue where there are commercial implications. An example in the 1980s was the way that IATA addressed issues with the bias of computerised reservation systems (CRS) and acted as an authority able to draft and impose a workable set of fair-trading rules. At the present time IATA is active with regard to several issues in the areas of safety, security, the environment and e-ticketing.

IATA has standing and special committees that address airlines, airports, cargo and other civil aviation and travel issues. For example, while ICAO has played a leading role in setting CNS/ATM standards through the workings of its Future Air Navigation Systems (FANS) committee, IATA

addresses issues concerned with the financing and investment requirements that arise when implementing such systems.

As well as looking ahead, IATA has many functions that are a legacy and still represent a foundation upon which many financial operational aspects stand. IATA tariffs were ticket prices set in the days when economic regulation was stronger than it is today. At one time all airlines issued 'IATA tickets', which were multi-layered coupons that made every airline ticket look alike. If a traveller conducted more than one flight, with different operators, IATA would process the coupons, applying pro rata rules for the distribution of revenue, through the organisation's ticket clearance system. This system still exists and handles almost all such work to this day. It is a vital part of the revenue management service department within every international airline, even if they are not IATA members.

Additionally, the IATA Scheduling Services are responsible for the development and maintenance of standards and procedures for the exchange of schedule data between airlines and airports and airport coordinators, at the six-monthly spaced IATA Schedules Conferences. The purpose of this voluntary assembly of both IATA and non-IATA airlines worldwide is to provide a forum for the allocation of slots at 'fully coordinated' airports and for reaching consensus on the schedule adjustments necessary to conform to airport capacity limitations.

On behalf of the Conference, IATA manages and publishes the Worldwide Scheduling Guidelines (WSG). These guidelines are developed in consultation with the airline and airport coordinator communities. IATA sums up its work with the words that its 'intent is to provide guidance on managing the allocation of scarce resources at airports on a fair, transparent and non-discriminatory basis'.

Throughout the immediate post-war decades almost all of the world's major airlines were members of IATA, and it was through this organisation that many commercial rules were created and implemented. The most unpopular was that IATA had a preferred fares structure that (according to those airlines that eschewed IATA membership) kept fares high. The degree to which IATA set fares is nowadays viewed less harshly, for while they certainly did contribute to competition being limited, they introduced sustainable revenue levels and provided additional services that set benchmarks that were often unrecognised, in terms of their importance, at the time.

One aspect where IATA has total control is the allocation of airline and airport codes. This is a small but vital harmonisation task, and at one time all airlines had a two-letter code that was a part of their flight numbering. Thus, KL123 was a flight by KLM (from the Netherlands), AF was a flight by Air France, and so on. Nowadays airlines are more numerous than the limited combination (650 or so) that can be arranged with two letters, so a

letter and a number are sometimes used and three-letter codes have also been introduced. Similarly, IATA administers the allocation of three-letter codes to airports, so LHR is London Heathrow while LGW is London Gatwick. Some are less easy to recognise, like YYZ for Toronto, Canada. By having these codes administered from a single repository, the many machines that handle airline flight data, baggage carrying airline and airport codes on bar-code tags, and so on, have a solid assurance of the presence of unique codes.

Charter operators work collaboratively with IATA on such issues as airport scheduling, but are not usually IATA members. Indeed, low-cost carrier (LCC) airlines are more often than not vociferously opposed to IATA, because they disagree with the discipline applied to fares policies in the past. Long-standing airlines, respectful of how IATA's mechanisms made slender operational situations more robust, are barely able to express their anger at the antics of these more contemptuous newcomers. IATA sits on the fence on such matters, and will engender debate and facilitate developments that it believes will be in the best long-term interests of the business. If that means the organization will have a diminished role, it will be because that is the way that the businesses have decided that things will be. At the present time, however, there is no sign that any pessimism should prevail in the corridors of IATA.

3.3 National authorities

Within each country, the national authority is the main point of contact with a regulatory body. Almost every country in the world has a Department of Civil Aviation (sometimes called DCA). It can be referred to as the DCA, with the head called the Director-General of Civil Aviation (DGCA). It is a part of the national 'civil service' and the staff will be partly specialists and partly governmental administrators who move between departments. In many large countries, the task is large enough to have a specialist body, within which staff are able to follow a refined career structure and where incoming and departing administrative staff are comparatively low in number. In the USA the specialist team is the Federal Aviation Administration (FAA) and in Britain the Civil Aviation Authority (CAA). It is a member of the national authority that will be a nation's representative in ICAO, and the organisation will have less clear but equally strong links with IATA.

Essential in all organisations, invariably, are two different groups. In the UK these are termed the Economic Regulation Group (ERG) and Safety Regulation Group (SRG). There are additional groups in all regulatory authorities for administration and personnel, for example.

Economic regulators have a role with regard to local operations, but this

has diminished in recent years in the USA and Europe, and this inward-looking role is diminishing elsewhere. Meanwhile, internationally the regulators are still responsible for guiding officials, from the government and airlines, on the content of bilateral agreements. An aviation authority can advise in situations where airlines are vying for traffic rights between countries, the right to impose conditions on aircraft entering the country from another country, slots at airports, and so on. In any solutions they have to accord to the 'freedoms of the air'.

The organisation is easily portrayed in an unfavourable light when it applies rules that try to represent a compromise that arises from political wrangling between States. There are instances, however, when the authority is acting upon international or moral mandates. The fact is that competitive businesses believe strongly in freedom of choice and action, and do not like constraints. Regulators therefore are often an easy target for grumbles and complaints. Because this is a serious, potentially destabilising, influence on the air transport industry, in most countries there are organisations that are granted the right to curtail overzealous regulation. In Britain the 'watchdog' with most appropriate access is the Air Transport Users Committee (ATUC), which is a forum of politicians, representatives of industry (airlines and airports) and academics.

Safety regulators are much more involved with day-to-day operations than their economic counterparts. They will apply directly, or with appropriate modification, the requirements of the ICAO Annexes. Safety regulators are empowered to demand access to facilities and records, and periodically they will check all safety documentation within airlines and at airports. They have a duty to audit and to feedback information, and whereas it was often the case that they would assist in developing solutions, newer powers mean that they are much less involved in solving problems. They can point towards examples of best practice and encourage the dissemination of information that they believe is conducive to safety, but nowadays they operate largely in a quality assurance role and not as consultants.

This is a part of the way that government-allied organisations have been reorganised to streamline their functions, to work with fewer staff and thus to impose a smaller overhead on what are increasingly real businesses, which were becoming critical of the way that regulatory functions were operated, given that they felt that their fees were unjustifiable. It is a difficult judgement to make, and to ensure that power is shared equitably there are organisations that will act as a 'safety valve' in that they will collect and process complaints, and are tasked to do so in a critical but progressive climate.

The influences of the economic and safety regulation services arise at many points in this book and will be described in greater detail at the

appropriate times. Meanwhile, it should be appreciated that the picture presented so far is incomplete without mention of the fact that most nations with sizeable aviation operations also have organisations dedicated to specific safety functions. For example, in large countries it is traditional to have a team of scientists and engineers, employed as civil servants and quite apart from the regulatory authority, whose job is to investigate aircraft accidents. They are thus empowered to question the integrity and capabilities of all organisations associated with aircraft accidents – even the regulators. In Britain it is the Aircraft Accident Investigation Branch (AAIB), and in the USA the National Transportation Safety Board (NTSB) has oversight of all transportation modes, including aviation. They disseminate preliminary, occasionally intermediate, and final reports on all significant incidents, so that the public domain is aware of safety issues.

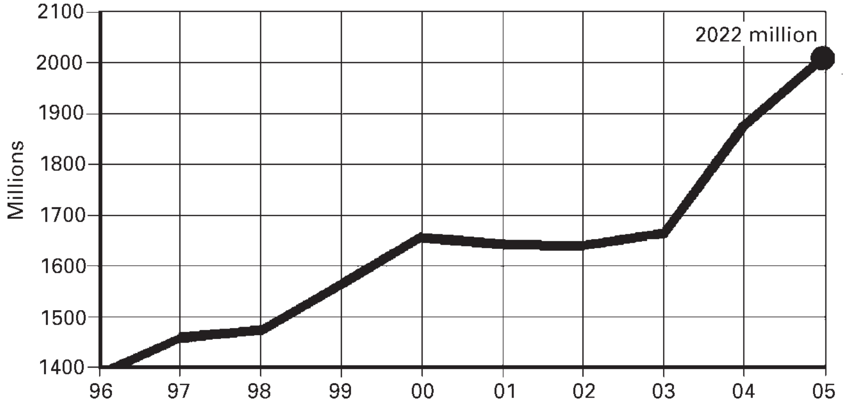
3.4 Service properties

It is important to keep track of the scale and characteristics of the air transport business. Each national authority collects and collates data on operations to/from airports, conducted by the airlines and other aircraft operators in their region of jurisdiction, and supplies information to the statistical bureau of ICAO.

The ICAO historically has been the best source internationally of all statistical data that define the properties of the services that are operated worldwide. The next examples are drawn from the annual statistical review that ICAO used to produce around August/September each year. However, from 2007 this procedure has been discontinued.

3.4.1 Service volumes

Figure 3.1 shows that passengers carried annually in all civil operations rose some 50% in the 10 years up to 2005, and in the last year for which data are shown, over 2 billion passengers were carried for the first time. The continuing popularity of air travel is the source of one of its most serious problems – capacity. Even today the vast majority of the world's population never uses an airliner, but as affluence extends then access to this mode of transport will be exploited. The potential for air travel is far from reaching a climax. It may be near its peak in some countries, such as the UK and USA, where the number of journeys per head of population is showing signs of reaching a plateau. However, in countries like China the explosive demand of recent years is expected to continue unabated as the nation's fortunes increase. Several other nations are in the same category. ICAO statistics show, for example, that China climbed from fiftieth place in 1979 to second in 2005.

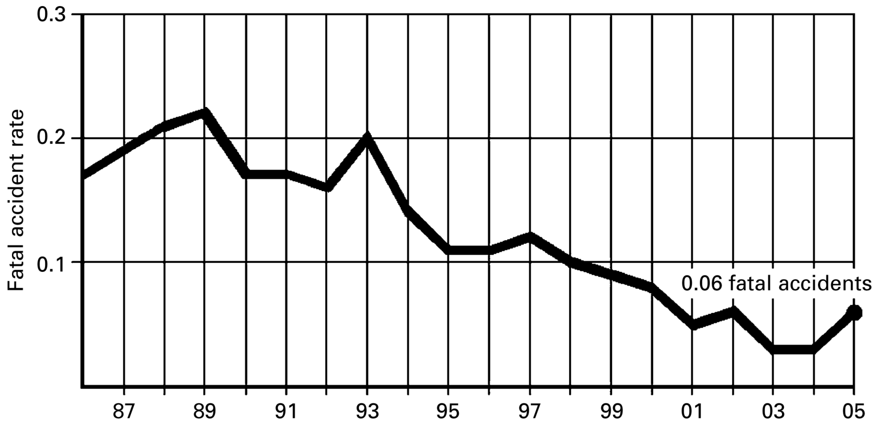


3.1 Total passengers carried, 1996–2005 (Source: ICAO Annual Review, 2006).

It has been commented that much safety regulation work, within ICAO and through the national authorities, concentrates on establishing and maintaining high standards. The plot in Fig. 3.2, updated annually by ICAO, has been the aviation safety benchmark quoted by aviation commentators and safety specialists for many decades.

The graph shows that, according to the fatality rate, safety levels do improve gradually. There are some setback years, but overall the trend has been maintaining a healthy, downwards, trend for some 50 years. Safety regulators recognise that they have to be proactive in encouraging legislative procedures that will arise from knowledge of issues and remedies.

One indication of the pivotal role of safety regulation is that ICAO Annexes require that key staff, and specifically aircrew, aircraft maintenance



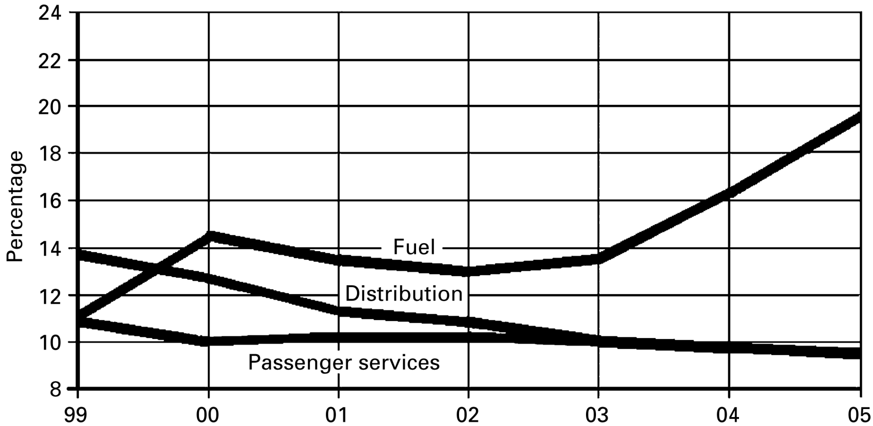
3.2 Fatal accidents per 100 million aircraft-km flown on scheduled services, 1986–2005 (Source: ICAO Annual Review, 2006).

engineers, air traffic controllers and dispatchers, are all trained to statutory levels of competence – tested by examination and periodically checked – throughout the world. These are the people that are effectively mandated as the real custodians of the world air transport safety record. Operations will be viewed and regulations modified as evidence emerges of where rule changes can be justified. Meanwhile the training, certification and monitoring of personnel licensing standards is a national responsibility and is laid down in national policy.

Finally, consider fuel costs. This is a contemporary topic, but even so it has the potential to be the most important influence on economic performance, and even on demand, and thus overall system operations. Figure 3.3 shows the way that fuel costs have changed, as a proportion of airline costs overall, over the last 10 years. This is indicative of the depth to which statistical data are collected and how valuable it can be to policy-makers in the industry.

It is possible to find more detailed statistics for individual operations in national accounts (the FAA in the USA and the CAA in the UK have extensive statistical summaries on their own websites, which detail current situations and historical trends).

Clearly ICAO is a vital source of statistical information, but there are equally valuable data sources, including the IATA and national authorities. The annual accounts of airlines and other aviation businesses are often of interest, but are less clearly reliable long-term sources of information, because they are a source designed to express the attributes of the business and to extol, rather than be critical – when necessary – of the business performance. This reflects an issue that arises as a more detailed view of the



3.3 Costs as a percentage of total operating expense, showing fuel, distribution and passenger service expense trends (1999–2005) (Source: ICAO Annual Review, 2006).

complete system emerges, because a stakeholder bias in a report will necessarily focus on the properties that are of interest to that subset of individuals. It is the international and national authorities that tend to gather, collate and disseminate the most useful of all reports that detail system properties.

3.4.2 International air service agreements

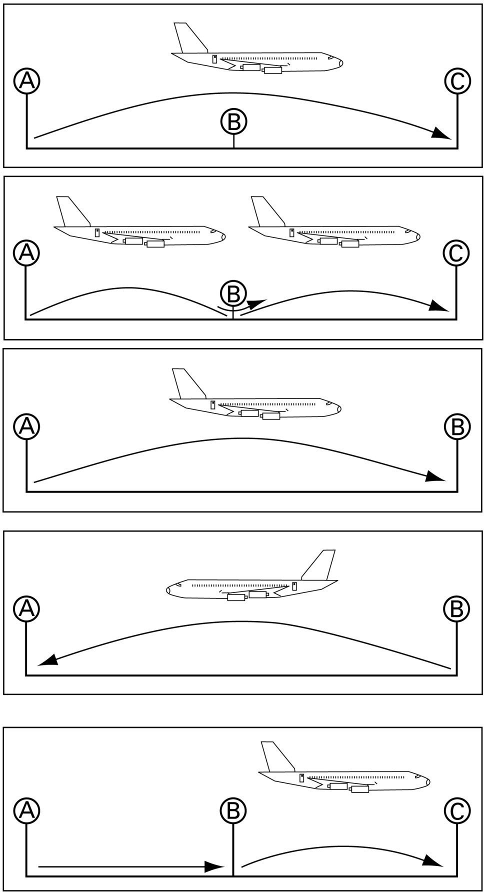
An issue that drew delegates to the 1944 Chicago Convention was that a concept in all aviation legislation was acceptance that nations hold 'sovereignty' over the airspace above their territory and over water adjacent to that land. The limits of airspace sovereignty extend much further than territorial waters on the sea, because they are arranged to meet where countries border a relatively small body of water. Over oceans there is no sovereignty as such, but one or more bordering nations will accept responsibility for acting as an airspace control authority, thus ensuring that internationally agreed safety mandates are met in these areas.

A consequence of 'sovereignty' is that people need permission to fly into and out of, or over, a nation's airspace. Overflying rights are sometimes taken for granted, but these can need careful pre-planning in some parts of the world. The right to fly an aeroplane over someone's territory if there are significant political differences can be a major instrument for a government to use in order to express its displeasure with a nation.

These issues led to the formulation of bilateral agreements, as already explained. In order to ensure accordance with international mandates these agreements incorporated the definitions of the 'freedoms of the air' that were drafted in 1944. At the Chicago Convention five ways of expressing how a country could have its rights to overfly or land within another nation – for passenger or technical purposes – were defined. These were called the 'five freedoms of the air' and are expressed diagrammatically in Fig. 3.4.

These definitions were adequate in the early days of long-haul operations, because such flights often stopped to refuel in countries between the origin and destination, and the freedoms allowed such 'technical stops' to be conducted in the name of safety but without the supplier nation losing traffic to a dominant carrier. With the emergence of intra-states, like the European Union (EU), where individual member states have their own airspace but now trade freely across national boundaries, 'deregulation' has taken hold, and this, and similar loosening of trade restraints elsewhere since the 1980s, has led to three additional freedoms being defined. These are shown in Fig. 3.5. They are sometimes referred to as 'freedoms of cabotage'. In the ultimate freedoms (the seventh and eighth), the country has virtually ceded the right to let anyone fly services within or to/from their nation.

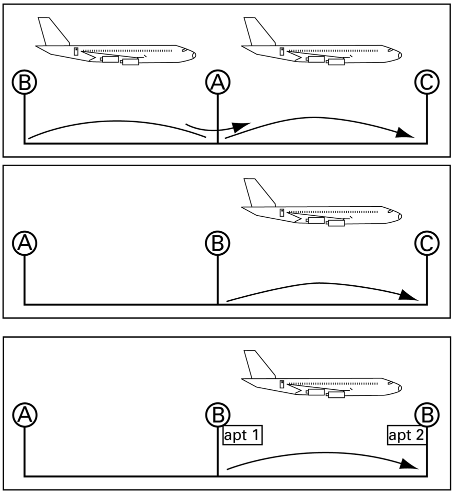
Europe is the most obvious example of where such liberal traffic rights are



3.4 The five freedoms of the air.

ceded, because an EU transport policy, implemented in stages throughout the 1990s, has been to annul all diplomatic constraints. For example, any EU registered airline can officially operate between any two EU nations. Some non-EU countries have joined in the spirit of deregulation and allow themselves, for air transport service purposes, to be treated as an EU nation, such as Switzerland and, to a lesser extent, Norway.

When an airline from outside the EU wants to fly into the EU and to carry traffic internally, there is more to consider. For example, an African airline might fly into Europe and stop at two locations, say flying to London via Amsterdam, and have an agreement to pick up passengers in Amsterdam and carry them to London. They might not be allowed to advertise this service under their own name, but if they coordinated the service with an existing carrier on that route the European carrier could advertise it for them. The service would be offered with the EU airline's code and would be



SIXTH – the right to carry passengers (or goods) between two foreign countries, by stopping or connecting in the home country)

SEVENTH – the right to carry passengers (or goods) between two foreign countries, without extending the route to the home country

EIGHTH – the right to carry passengers (or goods) wholly within a foreign country

3.5 Additional freedoms of the air.

an example of a wider practice, called 'code-sharing'. The basic right to operate such a service must be bound to a bilateral agreement.

Bilateral agreements have already been explained and ensure that where there is an opportunity for the sharing of demand between two nations, the airlines have the right to fly designated routes with designated airlines. They are more complicated in some cases; for instance, if a small nation faces a large nation, say with one and several airlines *in situ* respectively, then the bilateral agreement might limit the large nation to use only one designated airline or allow several airlines to serve from the larger nation, but limit the places that they can use. This is often called 'gateway' designation. Basically, large (so-called 'international') airports might be gateways, although there is always pressure to remove constraints and to allow smaller (so-called 'regional') airports also to be served directly. This is happening more and more as the large airports are becoming constrained through their success, having created demand that has filled all the capacity they can offer. Capacity is an attribute of the air transport system that has been managed, on the whole successfully, through regulation, but the situation could be about to change. In that regard, bilateral agreements will begin to change too, which is a good example of how laws are never static. Overall consideration of how the air transport business works as a system will play a part in finding solutions to the issues that are arising.

3.4.3 Deregulation

'Deregulation' was a milestone in regulatory affairs. It took shape in the USA in the late 1970s, where a wide debate considered a plan that refuted

the need for any traffic rights related regulation in the domestic sector. This concept saw the light of day on US statute books in 1980. Initially, US 'deregulation' applied to domestic operations only and all other aspects of air service regulation – access by international airlines, safety regulation, and so on – remained in place. Even so, it was an event that was to have worldwide repercussions.

Until 1980, in the USA all domestic airlines – as in all other nations at the time – had to hold a 'route licence' for each service they operated. If airline A had pioneered and operated Seattle to San Francisco, they had the licence for that route. If airline B decided it would like to operate the same service they had to apply for a route licence. The licence was only granted after a hearing, when the incumbent airline, and anyone else who had an interest in the case, could object and present their arguments. The USA prides enterprise and would often listen to an airline that was objecting to new competition with only limited compassion. However, if a route was being 'saturated' with many airlines (almost every airline wanted the most lucrative routes) the licensing body, the Civil Aeronautics Board (CAB), had to tread warily. It was becoming the norm to licence two carriers on major routes and more on very busy routes, but the 'pioneer' on the route often won concessions from the CAB, whose policies were increasingly under scorn from new and vigorous airlines that saw the established carriers as feather-bedded, inefficient and overprotected. The major argument was about routes, but there was also concern that the CAB was too draconian in the way it set and administered fares across the US airline network.

'Deregulation' abolished the CAB. Airlines within the USA (and that was US domestic airlines only, as non-US airlines were, and still are, vigorously denied US internal domestic flying rights) were able to fly where and when they wanted. They could also charge whatever fares they wanted. It generated economic upheaval and many of the well-established airlines disappeared. The 'mega-carriers' – principally United and American – grew and grew, but they did this often by buying up small airlines, who wanted to be involved in the new era. Airlines such as Ozark, Piedmont and Frontier, which had gathered their own adherents, were swallowed and lost (in their original forms at least, as marketing forays have reintroduced the names recently in appropriate regions).

Most important of all, there was a new breed of airline. Initially they started with big plans, came on the scene, boomed or then flopped spectacularly, none perhaps more so than People Express, whose fleet, with intercontinental-range Boeing 747-100s and smaller types, flew the lowest-cost domestic routes from the early 1980s. Some entrepreneurs attracted by the new opportunities decided to stage a more quiet revolution and have set some of the most astonishing records of all. Most notable has been Southwest, an airline that pioneered the idea of a one-type fleet. However,

they did not buy second-hand, but invested in the latest aircraft variants and built their business by offering the lowest fares in the hardest worked equipment on the continent. Other entrepreneurial developments included 'business-only' airlines – the other end of the demand spectrum – that offered widely spaced seats, at-seat service and premium fares, but none was really successful. Executives could use a business jet for little more cost and had additional flexibility in terms of when they flew and even where to. The business-only model does keep re-emerging, however, and its day may yet come.

Deregulation has been copied in Europe, with almost unhindered cabotage between all EU member states offered through successive stages of relaxation of the regulations. The aim has been to emphasise that Europe can be 'domestic' in nature, but for now the problems are manifold. With over two dozen countries and even with a common currency across many borders, there are adherents to the idea of a 'national airline' and to whom the thought that airlines that are almost household names could be swallowed by multi-national mergers is anathema. Europe now has some notable low-cost operators with hubs in many countries and has therefore pioneered the new paradigm, but the shifting sands are still moving at too great a pace to claim that a solution has been demonstrated.

It is not surprising to find that the same principles are being applied, often with great controversy, throughout Asia, Middle East, Africa, the Indian subcontinent, in Australasia and all around the Pacific. Nor is the concept unusual to the inhabitants of the former Soviet Union or China, where to see a commercial strategy driven by such blatant entrepreneurial flair would have been anathema in the harder days of totalitarian government. The consequence in all cases is exactly as it was in the USA, in that LCC operations emerge from locations that offer good 'hub' locations. The number of such airlines has multiplied rapidly since the year 2000 and there is virtually no country with more than one airport that now does not have an incumbent, or visiting, LCC.

3.4.4 Privatisation

The term 'privatisation' is often lumped with 'deregulation'. It is not the same thing. Privatisation is all about ownership, but what it does share with deregulation is the desire to press service providers to accept responsibility for investment and service issues, such as frequency of service and the quality aspects of whatever service is provided. Privatisation is arguably a route to more public access.

In many nations, around the mid-20th century, there was a clamour to 'nationalise' all major businesses. This meant that the complete shareholding was acquired by the government, effectively using public money to

buy the assets of businesses that the public would use; thus they would have 'ownership' and get the financial benefits that would otherwise go into private shareholders' pockets. Arguably, the sure-fire successes would mean that products were cheaper and taxation was reduced. With some businesses it worked, but with others it did not, and transportation was one sector where historical records suggest that it was, decidedly, a bad choice.

Having businesses like airlines in government ownership tended to set their organisations in concrete. They were unable to accommodate changes in working practices – much as many of the managers involved certainly tried. Their profitability plummeted and doubt was cast on the service quality of their products. Governmental interference was always mooted, as the airline's owner was also the organisation that was negotiating bilateral and other service agreements, and even the source of aircraft for the fleet. The USA was the only nation with a significant proportion of shareholder-owned airlines conducting daily business, but even there the access to routes was restricted by bilateral agreements, and certain carriers – the erstwhile Pan American and Trans World Airlines (TWA) most notably – become the de facto 'public' airlines. Deregulation did introduce changes that lowered protection for such firms and the belief is that their lack of accountability was what led to their demise. This is deniable, but what is not deniable is that in Europe the majority of growth in the airline sector was with what were often referred to as 'independent' carriers. These were privately owned, often as offshoots from travel companies, and were operating lower-cost, albeit very specialist, charter services where it was felt that a 'privatised' market could treat as competition. More access to the market would encourage better practices and fares would tumble.

The push for privatisation has led to the liberation of national airlines. British Airways (BA) was the first significant carrier to make the transition from nationalised to shareholder company, but there had not been an equivalent shift in any other EU nation up to early 2007. Many airlines have followed BA by attempting partial (rather than full) public ownership.

It has also been the way that airports and some service providers (especially air traffic control) have been forced to go, although in the latter case the UK example is being copied willingly, being a partial-privatisation initiative. The government keeps a minority of the shareholding (49%) but has greater proportional representation on the board. This gives them, effectively, power over policy. In such stark terms it does not sound terribly democratic, but as later notes will show this is an area where change is inevitable and very significant shifts in emphasis in management are felt to be necessary. There will be considerable risk, certainly financially, and the fear is that operationally there is also a risk in accommodating such change. The government is there, in the model adopted, to shoulder responsibility on some thorny issues. Meanwhile, investors can be attracted too. It is not

surprising, perhaps, that when the bids were assessed the UK government chose to select a consortium of UK-based airlines to take the majority shareholding. The view is that, as customers, they know best the implications of bad management in the business. It will take a decade or more to find out if this is true, such are the interesting times in which we live.

Airport privatisation has been another on-going story. In the UK the major airports were owned by the government and operated through a nationalised business, called British Airports Authority (BAA). To some it seemed a licence to print money, in that in the most prolific growth region, the south-east, BAA had almost all the capacity that was available ceded to its own organisation. BAA was privatised around the same time as BA, as the airline – British Airways – chose to be defined. BAA chose to be called just that – no longer its original title – the argument being that it was not wholly British as it had acquired the assets of other airports worldwide. As these notes were being written it was swallowed by Spanish investment, becoming a part of the Ferrovail organisations.

Most commercial airports were owned by local municipalities and were a limb of local government, but most major airports, and in some countries the majority of regional airports too, have been privatised. Those that have not undergone the change have been re-defined as a separate organisation, owned or partially owned by the local government, but operated as a business that cannot inherit from, or contribute to, municipal funds.

However, some airlines and some airports, because of the uncertain nature of the business, especially when traffic levels are low, cannot be run as viable businesses. For example, they may support communities where a pure cost argument mitigates against their existence, but the benefits they bestow are so valuable in socioeconomic terms that they have to survive. In Europe the Norwegian government subsidises airlines and airports that serve communities up and down the country's long and rugged, fjord-ridden, coastline, and likewise in the UK the services of airlines and airports in the Scottish Highlands and Islands are subsidised by the government. These examples serve to remind the reader that 'one suit does not always fit all'. There has to be the capability to absorb flexible policy and to allow some variation in an otherwise dogmatically applied doctrine.

This section has dealt with the major issues that have determined the qualities required of those who have been involved in national economic regulation in recent decades. The other front on which national regulatory policy has to be handled in a circumspect manner is safety regulation.

3.5 Safety regulations

Broadly, there are two models that can be applied by a national authority in terms of exercising their authority as a safety regulator:

- One is to apply onerous and detailed technical regulation rigorously, giving little leeway and showing no favour. This was the almost universal practice for many decades, but the model was challenged from the late 1980s.
- The newer, alternative, policy is to give participants freedom to interpret regulations that are principles rather than expressions of adherence, and to let the users apply the regulations within a safety management system (SMS) that they have created. In approving the SMS the regulator and the user will define criteria that the regulator can monitor and set attainment targets against each one.

Whereas organisations often used to look to regulators to influence their choice as technology delivered new capability, the new paradigm is that users have an obligation to seek, or encourage, new developments and to introduce them to meet their own aims.

What happens in aviation is not unique, and in setting out the principles involved it pays to consider an example more mundane than building or operating an aeroplane. If you build a porch for your house and it fails, it will have the potential to injure, maim or even kill people who are near it. If you build a porch without observing critical building instructions, and that error is discovered, you will be prosecuted. In this example the law attempts to protect the innocent and not to persecute the adventurous (although note how easily the wrong interpretation can be construed). Civil aviation regulatory policy is similarly contrived, because the failure of any part of an operation in civil aviation can carry consequences that will threaten the community as a whole.

The most important global yardstick used is the annual record of accident rate, which has already been shown and comment made with regard to the satisfaction that accompanies the fact that the statistical probability of an accident has diminished steadily over almost 60 years. There is a desire to maintain this trend, although the actual rate is now so low that obtaining a substantial improvement is proving to be difficult. There is a prognosis, however, that the demanding goal of a zero annual accident rate has to be regarded as an attainable objective, because if traffic levels continue to rise, the frequency of accidents will rise. The price of failing to approximate to, or reach, this demanding safety target will be significant to how the public perceive civil aviation. It is one of the reasons why safety regulation nowadays prefers a ‘be proactive’ rather than ‘be overbearing’ role.

Safety regulation starts with the approval of organisations and licensing of facilities and personnel. Hence airlines have to meet operating standards and qualify for (in the UK) an Air Operator’s Certificate (AOC) while airports have to qualify for an Aerodrome Licence. Equivalently, maintenance and other operational service organisations have to be

appropriately 'approved'. Similar methods are applied in all states. Hence, when an application is made to create any organisation whose operations will have safety implications (whether that be an airline, airport or contractor), the organisation must declare staff, by name, that are acceptable to the national authority, to fulfil certain leading roles. In effect, these are people who are empowered to act on behalf of the approving authority on a daily basis. They can be Chief Pilot, Airport Operations Manager, Head of Fleet Maintenance, and so on. They must keep a clear and complete record of their decisions and if any decisions that they take they feel are controversial, they are expected to discuss them with the regulator immediately. The national authority will look for patterns in these reports and might use them as a guide to whether operational issues are legislated suitably.

Deeper within organisations the responsibility for safe operations is vested in staff on a hierarchical basis. Pilots, mechanics and technicians, despatchers and air traffic controllers, to quote the most well-known examples, are given full responsibility in specific operational situations and expected to maintain currency of their qualifications through regular training. Their periodic checks might be conducted internally by a licensed individual, who in turn will be checked regularly by the national authority. They obtain their certificates of competency through a succession of training stages; these are principally stages that address, respectively, fundamental procedures, complex procedures and situations specific to the job (type rating of aircraft-related staff, station validation of ATC staff, etc). It is common practice for some operational staff in the regulatory organisations to be active within an organisation, perhaps as a fully qualified airline pilot, because that would have been what they were before they became a regulator and they can thus claim exposure to real-world issues, hazards and burning issues. It is a rare, but very carefully policed, situation that bears fruit provided mutual respect is maintained between the regulator and organisations. On the whole, such a policy contributes to such respect, and it can considerably shorten the time needed to invoke and clear suddenly required legislation.

While this layered approach is now a well-established practice and the procedures are well defined, the trend towards SMS-based regulatory power implies that a safety system can be run on many different lines, ranging from the established, rather authoritarian, approach to implementations that are less well structured and in which individuals at all levels take a more personal responsibility for monitoring and reacting to changing circumstances. As an example, this can lead to an airline engineer, on encountering an unexpected problem, formulating a unique solution. It will have to be countersigned, and thus checked by a colleague, but it might lead to a solution in less time than having to feed information through a chain of

command and awaiting the authorisation of an individual further up the hierarchy. The staff that have taken the decision in the organisation, in this case, would be duty-bound to report the details, and only upon hearing of the events does the technical authority decide if they need to respond or simply accept the work undertaken. This leaves regulators more free to regulate, rather than to interfere in daily decision-taking, and should lead to leaner and more cost-effective national regulatory processes. This approach has been used extensively and has worked well, on the whole, in recent years.

Many would regard this as a first-class example of how to apply a 'systems approach' to problem-solving. The individual in the firing line is left to exercise his or her own judgement, which will be based on experience, and yet he or she is not made to feel alone – the hierarchical system is still there to support those who prefer to seek advice. Responsibility has been passed down the chain of command.

3.5.1 Risk assessment

In respect of having a justification system for action or inaction, or to act as a stimulus for change, the most far-reaching principles in safety regulation are in risk assessment. It is a framework that is simple in terms of its philosophy and is a prime example of taking a 'systems approach', in that a key property of the system is recognised and managed through regulation. Examples of the latter are FARs (Federal Airworthiness Requirements) administered by the Federal Aviation Administration (FAA) in the USA and JARs (Joint Airworthiness Requirements) administered by the Joint Airworthiness Authority (JAA) in Europe, which declare objectives that govern the latitude for judgement in the design and operation of aircraft and their components. In assessing the applicability of procedures an organisation has to submit a functional hazard analysis (FHA) to the regulator. This can take many forms, but it will invoke several defined steps, and thus it might range from involving a panel of specialists with different but relevant disciplines to being a competent mathematical model based on acceptable data and analytical criteria.

These regulations are justified according to a numerically assessed level of risk, which must be shown to surpass a threshold of acceptability in the event of a particular failure. It can come as a surprise to find that an acceptable level of failure is associated with such an event as an aircraft crash. Quite simply, to say that an aircraft must never crash is to say that aircraft should never fly. The four criteria in Table 3.2 are used to assess a possible failure in any system, within or supporting an aircraft's (or several aircrafts') operation:

- A minor failure is one that has no impact on the actual operation.

Table 3.2 Acceptable rates of failure

Failure effect	Acceptable rate of failure
Minor	1 in 10^3 hours (or 10^{-3} per hour)
Major	1 in 10^5 hours (or 10^{-5} per hour)
Hazardous	1 in 10^7 hours (or 10^{-7} per hour)
Catastrophic	1 in 10^9 hours (or 10^{-9} per hour)

- A major failure will have an impact, but it must be so well understood that anticipatory procedures, or system redundancy, has been used to make the failure survivable without serious consequences. An example would be the loss of an engine at the safety decision speed on take-off.
- A hazardous failure will be investigated in detail. Good design practice is to avoid this category. Thus an aircraft wing will have multiple-spars so that the failure of any one, while it will have an impact, will be survivable. If the failure was undetectable in normal service, the inspection regime, imposed as a condition of the certificate of airworthiness, should ensure there is an acceptable likelihood of it being found by a mechanic. If the investigated potential cause of a hazardous failure can be eliminated by design, re-design is often regarded as a necessary adjunct to getting an airworthiness certificate.
- A catastrophic failure will be assumed to lead inevitably to the loss of the aircraft and all of its occupants. The acceptable failure rate of 1×10^{-9} per hour suggests that, on average, a catastrophic failure will occur in every 1000 million flying hours. This is equivalent to about 12 000 aircraft flying 24 h per day, every day, for 10 years.

Traditional engineering design is governed almost exclusively by the desire to maximise or minimise the value of a controlled issue; this is then expressed as an *efficiency*. However, systemic approaches, like those used in technical regulations that address design and operations, encourage the development of solutions that meet objectives with the best use of resources. This defines the *effectiveness* of a solution. This is mentioned because, all too often, it is assumed that engineers and operators look for a high-efficiency solution, at the expense of good performance in all other regimes. In good design, risk-assessment procedures will ensure that all the necessary qualities are taken into account and balanced. Risk assessments (often called 'safety cases') are an essential component of a safety management system (SMS), and without the capability to perform these functions any operational team will be regarded as deficient.

3.5.2 Human factors and safety

Trends in accident statistics in the 1960s showed that aircrews, even when competently trained, occasionally set up flight conditions that lead to disasters. Two trends emerged.

First, a crew can set up systems controls that can be read ambiguously such that the aircraft does not do what they expected it to do. However, because they have not monitored it adequately, they are too late in responding to the unexpected situation when it does arise. This is not so much a failure as a 'blunder'. There is a strong body of opinion that such situations can be controlled, to a reasonable extent, by improvements in design or by installing monitoring systems that will react to such a mistake. Design requirements have been improved and have been reviewed and changed considerably over time. The advent of smaller crew sizes and more automated and electronic-based control and display systems has invited the chance of less monitoring and greater ambiguity. Safety regulators make the designer as responsible as the user in respect of performing human-factor related safety risk assessments in such areas.

Second, it was recognised that fatigue plays a large part in many human failures. A reasonable palliative, according to safety regulators who mulled over the causes of accidents many decades ago, was that crews should not be asked to fly so many sectors, or so many hours, in a single duty period, as their judgement might be impaired by natural fatigue. Crew flight-time limitation (FTL) regulations ensued and have been refined over the years. Tables 3.3 and 3.4 are extracted from UK practice and exemplify what is done worldwide.

There is considerable additional detail to such regulations, but the overall detail shown here exemplifies how a regulation should ensure that a crew is well rested, is thus less prone to suffer fatigue and hence much less likely to commit a blunder. Regulation cannot eliminate the causes in such cases, but in minimising the chances, the assessed likelihood of such an event is acceptably reduced. There are few industries that have effected such a wide range of legislation and combated the potential effects of complacency as well as civil aviation. It would be unwise, however, to think that the system has reached, in any sense, a point of perfection.

Within design and operational sectors where equipment is used, ranging from avionic systems on aircraft to the installation of lighting and navaids systems on the ground, and extending out so far as considering the impact of on/off-airfield developments on aerodrome operations, the operator has to conduct a personal risk assessment. Risk assessment involves the identification of safety cases, plus the application of accepted operational knowledge or the inclusion of analytical assessments, that will allow the regulator to see

Table 3.3 Maximum flight duty periods (FDPs) for acclimatised crew (defined as those who have adjusted to the time zone from where they commenced their regulated period of duty)

Local time of start	Sectors							
	1	2	3	4	5	6	7	8+
0600–0759	13:00	12:15	11:30	10:45	10:00	09:30	09:00	09:00
0800–1259	14:00	13:15	12:30	11:45	11:00	10:30	10:00	09:30
1300–1759	13:00	12:15	11:30	10:45	10:00	09:30	09:00	09:00
1800–2159	12:00	11:15	10:30	09:45	09:00	09:00	09:00	09:00
2200–0559	11:00	10:15	9:30	09:00	09:00	09:00	09:00	09:00

Table 3.4 Maximum FDPs for non-acclimatised crew

Length of preceding rest (hours)	Sectors						
	1	2	3	4	5	6	7+
Up to 18 or over 30	13:00	12:15	11:30	10:45	10:00	09:15	09:00
Between 18 and 30	11:30	11:00	10:30	09:45	09:00	09:00	09:00

that the possibility of a failure, and the consequences, are in accord with the published acceptable rates of failure.

These developments have led to a large increase in the number of so-called safety consultants that populate the aviation scene today. They are often specialists who have witnessed the evolution and application of these new ways of combating threats to safe operations.

3.6 Security regulations

These are not particular safety regulation issues for, while it is convenient to associate them in this portion of the presentation, in most nations the security legislation pertaining to aviation is lodged within government departments that are concerned with national affairs. Security, for example, is handled by the UK Department of Transport, while immigration is handled by Customs and Immigration Control. Since late 2007 the services have been re-organised and now perform the same duties in a more integrated manner, and are referred to as a border control organisation. In the USA the Department of Homeland Security takes the lead on security issues and immigration is the responsibility of the Customs and Border Protection Agency.

Although the security of air operations is an aviation matter, the effectiveness in applying security measures protects the liberties of

individuals and the safety of people on and around air operations, whether they are associated with the business or not. Airline and airport operators are liable for prosecution if they do not comply fully with the requisite standards of national security regulations. Airline, and especially airport, security regulations affect many more staff than might be imagined. At an airport, for example, it might be necessary for every telephonist that takes incoming calls to be trained to collect relevant details when they receive a threatening telephone call. Such vigilance can help to maximise the effectiveness of any security response. The paraphernalia of security, with archway metal-detector (AMD) installations, X-ray scanners, and so on, is the evident end of the system and is designed not only to detect unwanted articles but to deter people who pose a security threat. There are many other checks, such as sniffer dogs and photographic and radiation-based analysis systems, that will be used in various places. In some countries, air marshals, covert armed guards who travel as ordinary passengers, can be injected into passenger manifests and might be unknown to everyone that deals with a specific flight.

3.7 Environmental regulations

Environmental regulations are growing fast and becoming a major concern to aviation. Most environmental issues are aligned to planning consent and conditions. They can therefore be administered locally and very parochially. It is quite possible that, wherever one is in the world, the conditions applied at one airport will be different to those applied at any other airport.

There are ICAO Annexes that define noise certification requirements for aircraft and that set environmental guidelines. Aircraft manufacturers cannot certify an aircraft that does not meet requirements for peak approach, take-off and sideline noise levels. The requirement is refined periodically and has called for a substantial decrease in the allowable noise over several decades. This has been a fine balancing act, representing the best interests of the general public and ensuring targets are technically attainable without imposing onerous conditions that will impact the ability of aircraft operators to offer services. Each successive generation of aircraft has been significantly quieter than its predecessor generation, but the margin of improvement diminishes as the engine noise level reaches a level similar to that of the noise created by the aircraft's structure. There are some doubts about how far the regulation of noise at the design stage can be pushed further.

An airport can mandate aircraft to meet certain noise standards and thus may refuse to accept operations by some older aircraft types. This is not uncommon. A compromise sometimes is to impose restrictions, such as times of operation and frequency of services. Additionally, the airport

operator – if they have noise monitoring equipment – will reward good noise performance and even apply financial penalties on those who exceed declared noise thresholds.

The question of air pollution, which was once visible sooty trails behind aircraft, has not diminished, although the actual exhaust trail is less visible nowadays. The most problematic gases – oxides of nitrogen as well as carbon dioxide and carbon monoxide – are analysed in engines at their test phase, and are monitored in service to ensure that targets are met. As this book was going to press the long-heralded 'carbon-credit' scheme was unveiled, which requires airlines to respect targets and to pay fines if their carbon emissions can be shown to be over the targets. The stringency of these will rise with time. It is called a 'credit' because of the way that the system is used to measure the carbon emissions of all airline operations, such that if electric baggage carts and buses were used to ferry baggage and people from aircraft at an airport, that could act as a positive credit, compared to a negative credit for a carbon gas-emitting aircraft.

Airports also face the often onerous complexity of land planning regulations. In most countries, these will require that all development plans are submitted and approved before development can commence. This takes time, and time can be a valuable commodity to an organisation that wants to act quickly. However, these rules and processes affect everyone and all developments, and all airports have had to learn to live with the fact that major developments will be the subject of a public inquiry and there could be the additional hurdle of an environmental impact assessment (EIA). These measures assure the public that the airport is being developed with accountability and with regard to issues such as wildlife and noise management.

All regulatory processes are designed to ensure that the needs of those affected by the air transport system as it performs its daily service are taken into account, and thus that any imposition on operations is for a justifiable reason. The sheer volume of regulation nowadays can bewilder many newcomers, but the situation is unlikely ever to diminish in complexity. In viewing the system overall it will be necessary always to keep regulatory constraints in sight.

4
Operational environment

Abstract: This chapter introduces systems that comprise the operational environment. It is devoted to flight-related elements, with commercial systems withheld until chapters where the business factors they address are more evident. Equipment descriptions are at a functional level, concentrating on what information is detected or conveyed, and the various qualities of performance that determine usefulness. The qualities are linked to safety regulation, and these will emerge in later chapters as influential in terms of achieving global interoperability, and managing failure effects on safety in operations.

Key words: communication, navigation and surveillance (CNS) systems, automatic flight control systems (AFCS), electronic flight deck, electronic flight information system (EFIS), flight management system (FMS).

4.1 Introduction

The third, and final, 'environment' is neither natural nor regulatory. It is also very different, being an assembly of components created specifically to enable air transport operations. These components are some of the most high-technology devices of their era, and in this chapter the descriptions are kept at a functional level by concentrating what information they are designed to convey, or determine, and various qualities of their performance. This can mean considering the errors in sensors, the limitation in coverage of communication systems, the way that capability is affected by failures, and so on. These are the kinds of qualities that determine the usefulness of devices. The relationship between qualities might be related to the way that the system works, so in a few cases relevant inner nuances will be explained, but this is well below the level that a technician or designer has to be able to probe. In keeping an eye on operational qualities, the operational environment can be related to the other environments and other elements of the air transport system.

Inevitably, this chapter is an amalgam of many discrete units, and each has been allocated a description within an overall framework. The coverage has considered only operational systems that meet needs associated with current airborne operations.

If a genuinely broad view of operational environment was conducted, the chapter would also consider the commercial systems that govern processes preceding day-to-day operations. The most significant of these is the computerised reservation systems (CRS). Their role in changing the way that financially orientated aspects of operations are assessed and handled is acknowledged, but they are embedded within the airlines and hence they are considered alongside the commercial objectives they address in Chapter 6.

The chapter does introduce some embryonic systems, and the difficulty has been to ensure that those introduced are the ones that will survive on-going trials. In this innovative sphere that has proved to be a very difficult choice.

4.2 Evolution

The previously presented account of legislative issues has placed considerable stress on why the legislative system is never stagnant. By comparison, the operational infrastructure considered in this chapter, it has to be admitted, has been relatively static, in that what was used in the 1940s was still unaltered and in use 50 years later. However, in the last few decades the changes have been profound, and most of what was around in the 1940s and is still here today seems unlikely to remain either in a prime position or even to survive at all. Very radical change can be expected.

That change will arise from the exploitation of digital electronic developments. The whole of the operational infrastructure scoped in this chapter has depended on electronic systems development, and until the beginning of the 1970s that was almost wholly analogue technology, meaning it was based on electronic systems that used continuous signals (either radiated into space or passed along wires). Since the early 1970s the industry has developed systems that used pulsed, or digital, signals. The technology behind this is specialist and fascinating. Compared to the previous generation devices, digital systems tends to be smaller, more reliable and even cheaper. They can manipulate the pulses through electronic processors – microprocessors – that are familiar to all of modern society as the digital computer, which can be 'programmed' to do its job. While the equipment is hardware, the programs that reside within are its software. Some four decades have passed since digital technology began to affect the way that systems worked within the air transport operational environment, and it is now that we are on the threshold of seeing how it will reconfigure the environment. The changes in prospect are very profound.

Overall, it has become accepted that three elements make up the operational environment – communications, navigation and surveillance – which are referred to today as CNS. This nomenclature is used to structure the remainder of this chapter.

4.3 Communication, navigation and surveillance systems

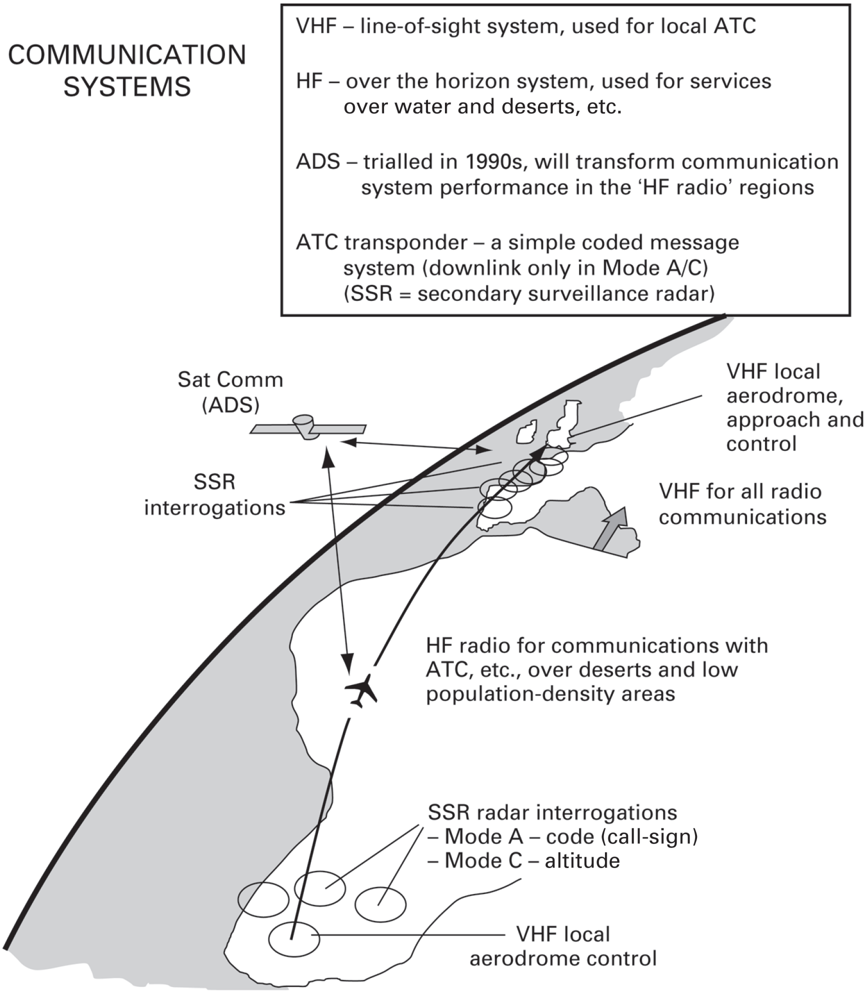
The next few pages will look into current CNS technologies, considering individual ‘systems’, in terms of what information or capability they provide, but without considering their technical attributes in depth. Each is described in a way that will generate a better understanding of why it evolved, and what it has provided includes consideration of its operational strengths and weaknesses.

4.3.1 Communications (see Fig. 4.1)

Wireless-telegraphy (w/t) and *radio-telephony* (r/t) are two ways of conveying information by wireless. The first system, w/t, is a wireless-based version of the telegraphy system that was used throughout the 19th century, where messages were transmitted using discrete signals, such as the dashes and dots of the Morse code. The system was able to convey information through conditions of poor reception, and while it was bulky it needed less power than a voice-carrying system. These devices were used in the 1930s and phased out by about 1940. It can be argued that the discrete signal system is re-emerging with the advent of digital radio, and technology has a habit of recycling ideas, but modern discrete signal radios are used in a very different way.

The r/t system used a radio system that transmitted a voice message as a continuous signal. The signal characteristics were modulated at the transmitter in such a way that the receiver could reproduce the transmitted voice. This was used as radio broadcast in the 1920s, but needed huge transmitters, and it was only when compact radio systems that could be installed in aircraft were developed that the system arrived in aviation.

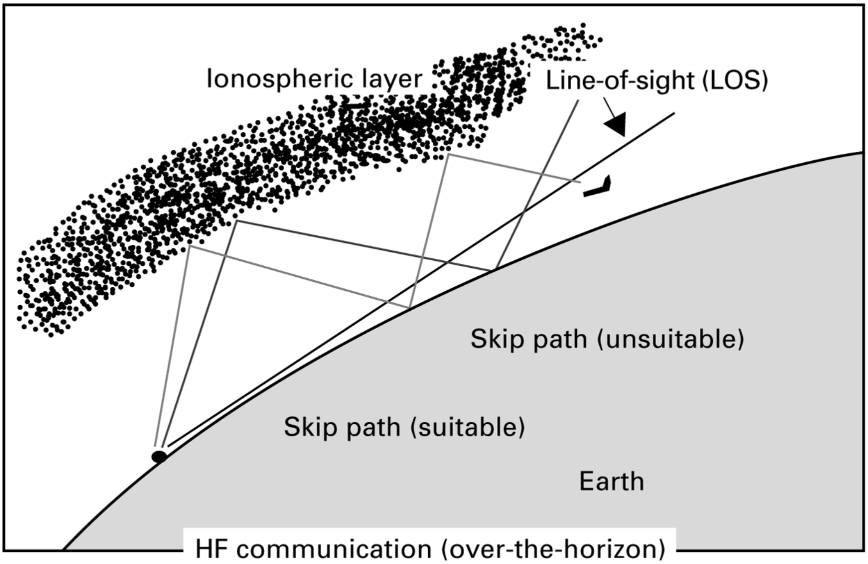
The *very high frequency (VHF) radio* is the continuous-signal radio-telephony (r/t) system that emerged in the 1940s. It met the need for air/ground and air/air communications to be achieved using voice messages. VHF wavelengths propagate roughly according to line of sight (LOS), so the usable range is a function of aircraft altitude, although terrain can also play a part in terms of coverage. The system uses press-to-transmit (PTT) buttons, as only one user can transmit a message at any one time. When a radio system is used by a large number of aircraft, the ability to convey all



4.1 Summary of aircraft communication system options.

messages and safety-related acknowledgements in a timely manner can limit the strategies open to users. VHF is widely used, but its limitations do impose constraints on operational capability in busy airspace regions. All VHF radio communications systems are installed under local aviation authority approval. (They can be eavesdropped by the public, but to transmit in the allocated frequency bands is a criminal offence.)

The *high-frequency (HF) radio* (see Fig. 4.2) has an operational utility that is broadly the same as VHF r/t, but the radio-wave propagation, which includes reflection from ionised molecular layers in the upper atmosphere, allows over-the-horizon (OTH) communication. HF r/t has become the



4.2 High-frequency (HF) radio communication usage.

commonplace system to use over oceans and sparsely populated areas and has held this role for over 50 years. The system has complex propagation characteristics, but the nuisance of unpredictable reception is a limitation that has been acceptable, given that traffic conflict situations are minimised in the airspace where it is used, so radio traffic needs are also reduced. If aircraft movements are more densely packed in remote skies the HF r/t system will become a limitation on strategic airspace utilisation options. Like VHF systems, HF radio installations have to meet local aviation authority approval. An adjunct to the HF radio is a device called *Selcal* (selective calling), which is installed on aircraft and will recognise a radio call carrying a short digital code that is unique to the aircraft. This allows crews on long-range operations to fly without their head sets; they respond to a chime from the Selcal unit, which is emitted when a radio message is received.

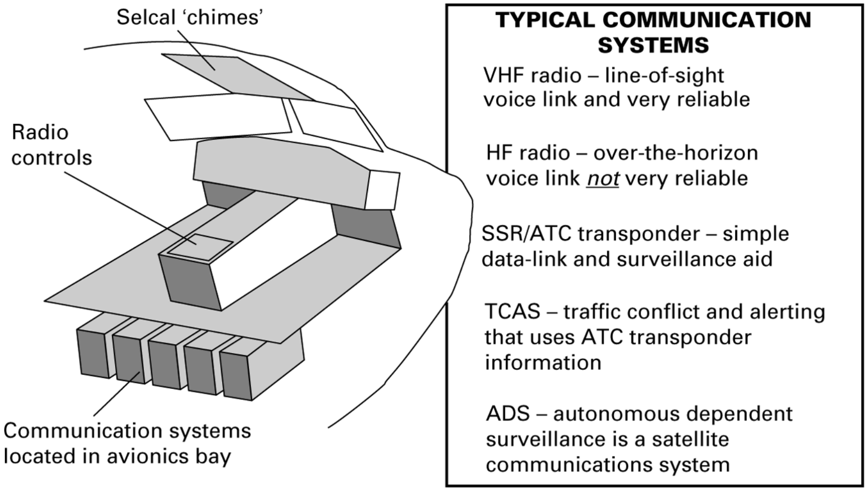
The *aircraft communication addressing and reporting system* (ACARS) is a digital data link that uses a VHF radio system – hence LOS application only – but because it is digital and not analogue based, it conveys data and not voice. It has been implemented, appearing first in the late 1970s, and adopted slowly over 20–25 years to allow airline flight operation staff to communicate directly with active aircraft. ACARS is based on a ground-based receiver/transmitter network. An independent authority, Arinc, installs the ground-based infrastructure and in so doing meets all statutory regulations and then operates the system on a commercial, non-profit making, basis. Thus, an aircraft anywhere with ground station coverage (almost all continental masses have been covered progressively since the

mid-1970s) can transmit digital data that will be received at a local ground station, and the destination address carried within the message will allow the data to reach the desired recipient(s) through the existing Arinc-based ground telecommunications network. Such digital data-link technology (widely used in military service) has contributed to improved operational efficiency in airlines, but because the system is a subscription-only commercial system, it is not suitable for general operational use, e.g. by the ATC system. The system conveys digital messages that can fulfil a variety of operational needs, from delayed passenger booking details for commercial recipients to providing aircraft systems health data to engineers.

The *secondary surveillance radar* (SSR) is described later, under surveillance systems, but it is, in effect, a simple data-link and thus a communication system with less capacity but equivalent functionality to ACARS. Mode A/C *transponders* have been mandatory on aircraft in controlled airspace for some 50 years, and the latest transponder-based system, Mode S, has become mandatory in the majority of airspace in the last few years. Mode A/C was defined in such a way that it carried only two pieces of information – aircraft identity (Mode A) and aircraft level (Mode C). Mode S is functionally similar to the ACARS system, as it is able to carry bursts of digital data that can convey complex messages. It is suited for conveying ATC-based messages, as SSR installations are rigorously regulated under the auspices of ATC service providers. The SSR is a digital message relay system and does not carry voice messages.

Autonomous dependent surveillance (ADS) is a system introduced relatively recently that is named, and extolled, for its surveillance attributes. Rather like ACARS it is a general-purpose digital data-link system, but this time it uses satellite transmitters/receivers and has worldwide coverage; it is a non-commercial service. There are three types of ADS and these are being evaluated and developed at the time of writing, the first operational exploitations having been explored over the Pacific Ocean in the late 1990s. Initial applications are as a unit to convey aircraft position and flight path information – hence the 'surveillance' title – but the greater data capability will be used in due course. This is the justification for describing it as a communication system. ADS seems likely to be the most commonly used system to transmit/receive digital messages in long-haul operations by 2010 and could be introduced rapidly in shorter-range operations, thus becoming the dominant communication system in the 2015–2020 period.

In summary, the communication scene, which was almost unchanged for some 50 years, has suddenly begun to change and the leading developments have been in SSR and ADS systems. Their capabilities are yet to be fully proven, but limited-scale evaluations (Project Capstone in Alaska has been a very notable demonstration of what ADS can achieve) leave little doubt that these are the communication systems of the future. ACARS has become well



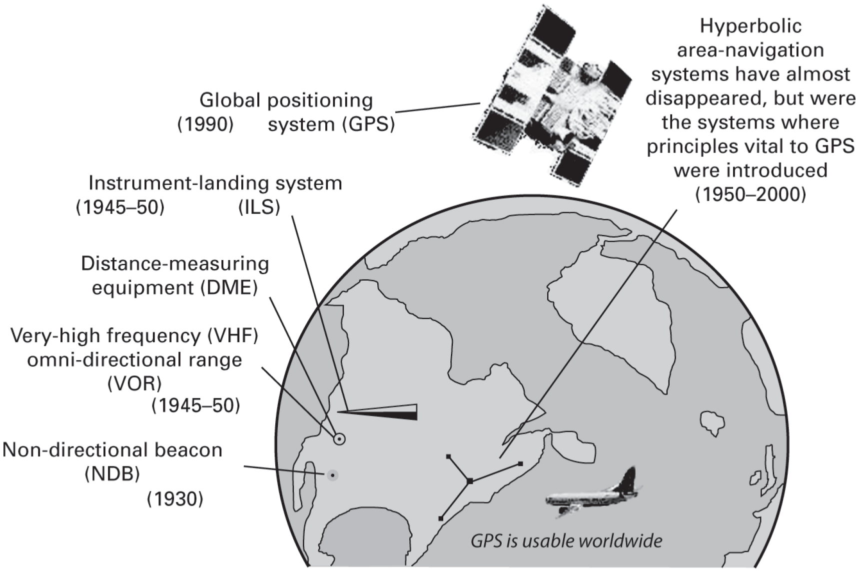
4.3 Radio communication on the flight deck.

established and its impact in the commercial sector is a lesson for the non-commercial sector. The VHF r/t radio has been 'overhauled' in recent times, with digital transmission replacing analogue in prospect, which brings reception and cost benefits; this may be the way ahead in the voice communication sector. The digital data-link seems certain to develop a new set of applications as it will allow computers to talk to computers. Mode S/SSR and ADS are poised to make the future communication systems field unrecognisable to those familiar only with r/t and elementary SSR applications. Radio communication on the flight deck is shown in Fig. 4.3.

The next section takes an equivalent look at navigation systems.

4.3.2 Navigation (see Fig. 4.4)

The *radio range* was the first en route radio navaid in civil aviation and was withdrawn from use by the 1960s. The device set some operating concepts that are a legacy and make a useful stepping-off point in this review of systems. It required a ground-based transmitter and an airborne receiver with a directionally sensitive antenna. The transmitter worked in a radio band that has been largely abandoned by the aviation community (the next system, NDB, being the only device that still operates in the same waveband). It created a number of sectors (or lobes) within which there were different Morse code messages (an A (dot–dash) or an N (dash–dot)), and the antenna configuration allowed them to overlap at their edges. The aerial could be adjusted to make the overlap occur in four directions from a ground station, or beacon. These were detectable by an aircrew with a



4.4 The evolution of radio navigation aids.

receiver as a Morse signal at the edges of the overlapping course, where the signal was continuous. The crew could thus be guided to fly to/from a ground beacon and this capability led to ATC clearing aircraft to fly routes that were defined by successive radio stations. They were usually about 70–80 miles apart, representing about 30 minutes flying time in 1930s aeroplanes. They were usurped by the VOR, which is described later.

The *non-directional beacon* (NDB) (or *automatic-direction finder* (ADF) for the on-board component) is the only navigation system that survives from the 1930s era. It is not recognised in regulations as sufficiently reliable for primary navigation use in civil aviation, but with many thousands of beacons available, most airliners still carry an ADF receiver and will use it to cross-check other navigation systems or to provide pre-visual clearance to an airport. In this application the system is often called a *locator*. It has survived despite the fact that it suffers from interference and when it provides guidance towards a beacon it does not state the direction from which it is approaching. In this regard, it is no different to a light beacon (or maritime lighthouse), but it can be received in all weather conditions (interference permitting). It is cheap, reliable, easy to install and maintain, and requires little power. All installations still require regulatory authority approval.

The *VHF omni-directional range* (VOR) (beacon) emerged in the 1940s as the navigation aid that could usurp the NDB and the radio range. It is interference-free and does provide an indication of course when flying to or

from a beacon. Many thousands are installed worldwide and they are still the main source of radio-position fixing used by most airliners and all other commercial aircraft. They are numerous because they have been supported as the preferred ground beacon by ICAO since the late 1940s. The VOR uses the VHF radio (hence it is LOS and almost interference-free), but compared with the NDB, the ground stations are more expensive and as reliable, but more fussy about terrain and objects near their site. They are complex units and can be described as a radio-based lighthouse, which emits not just an identifiable beam but a signal that has strength (radio amplitude) and colour (radio frequency) variations that a receiving unit can differentiate in order to determine their precise bearing from the ground station. This means that an air route between beacons can be aligned in any direction and a crew (even an autopilot) can select a course (called a radial) that they are guided to fly precisely. The ground stations are expensive to maintain and installations must be under close supervision, with appropriately qualified staff involved. This is almost a disadvantage, as the army of radio technicians needed to maintain a nation-wide system of VORs is often a large burden on airspace service providers. The VOR faces an uncertain future, because of its cost of ownership for the operator.

The *distance measuring equipment* (DME) is a radio device that will indicate on a numerical read-out the distance to the ground station (within LOS) operating on the appropriately selected radio frequency. The VOR and DME are often co-located on the ground. The DME has been co-located with VOR and ILS (to be described) and has gained popularity over the last 50 years. Initially DME receivers were very expensive, but their cost has reduced greatly since the late 1970s. It is therefore widely used and it is possible that, while DME installations will decline in number if VORs are removed from service, many installations may survive for the simple reason that this is a device that may have a 'new role' as the newer navigation aids come on stream. There is not a great deal to say with certainty about the system's future, but it does not appear to be quite so bleak as that of the once all-pervading VOR.

Area-navigation (R-Nav) systems are enigmatic, because what were R-Nav systems have disappeared and what has replaced them is said to have R-Nav capability. This paragraph is concerned solely with now defunct systems that form a legacy. The most successful systems were developed to guide bomber crews in the early 1940s and the systems that survived as commercial systems were *Loran* (long-range navigation) and *Decca Navigator* (a proprietary system owned by the UK company of the same name). They used a set of ground-based stations, typical four units with one master and three slave stations, which emitted HF radiation and were thus receivable beyond LOS. The ground stations were linked by land lines that ensured signals from the slaves were coordinated in time with signals from

the master; all four radio stations had a dedicated radio frequency and the receiver had to be able to collect the information from all four. The relationship between the master and one slave created a pattern that was a series of hyperbolic lines aligned perpendicularly to the line between the two stations. (The only way to appreciate this relatively complex situation is to imagine two pebbles dropped into a pond and to watch the ripples expand from each point. If the pebbles are dropped at the same instant in time the ripples will meet at the mid-point, and as they overlap, the point of intersection will be a straight line perpendicular to the line between the points where the pebbles entered the water. If the pebbles are not dropped simultaneously the ripples will meet at a different point and the intersection of the ripples will extend from that point as a hyperbolic line.) Loran and Decca receivers in the 1950s and 1960s were only able to provide a set of numbers that a navigator had to interpret and plot on a chart. There were some charts that could be mounted on a carriage and stepper motors moved a stylus to the aircraft's position, but the mechanical nature of these required that the map was 'distorted' and flying a straight line generated a curved line on the chart. This stopped the systems in their tracks; they were overtaken by more user-friendly devices (such as INS).

Even so, hyperbolic systems have been gradually usurped. The last Decca station was withdrawn from service in the 1990s and Loran has been under threat of closure since 1990. They have deserved mention because their legacy is immense, as will become evident when satellite-based navigation systems are considered.

The *instrument landing system* (ILS) is a highly directional guidance system with horizontal and vertical guidance components (called a localiser and a glideslope) that provides precision guidance down a glide path (typically from 20 nm or less distance) to the runway. It was developed in the late 1940s and accepted widely almost immediately. Compared with the only option at the time, which was a radio talk-down from a radar controller on the ground, the system was very cost-effective. A talk-down system could only handle one aircraft at once, or more if there were more workstations and controllers, but both solutions were expensive and had runway approach capacity implications. The ILS remains available at the majority of leading airports, often with several ILS installations at each airport, with one for each runway and each runway end. It provides 'straight-in' guidance, at one glide path angle only (which is rarely a problem), and it is reasonably interference free. The radio frequencies allocated to the system are in demand for other uses, so the World Telecommunication Union (WTU) keeps indicating that it cannot protect the ILS radio wavelength spectrum forever. The ILS is a system whose days are almost certainly numbered, but as yet a replacement has not emerged.

The *microwave landing system* (MLS) was supposed to be the successor to

the ILS. Its signals can be interpreted to guide an aircraft in a similar manner to the ILS (i.e. on a straight course and at a predetermined glide path angle) or it can be used to guide an aircraft on any three-dimensional path in a wedge-shaped sector that is based on the touchdown point. It is rarely seen, however, as airlines and airports have not seen fit to invest in this system. The specification for the MLS was released in the early 1970s and its development occupied almost a decade, which had it ready in time for widescale use by 1990 and the complete replacement of the ILS by 1995. Nowadays, a licence to manufacture the MLS is almost an embarrassment. This is an example of where technological acumen was difficult to judge and proved expensive for those who accepted the challenge. The emergence of satellite-based navigation systems in the 1990s was not unexpected, but the scale of the new system's dominance was a surprise. The MLS has been the most notable aviation casualty.

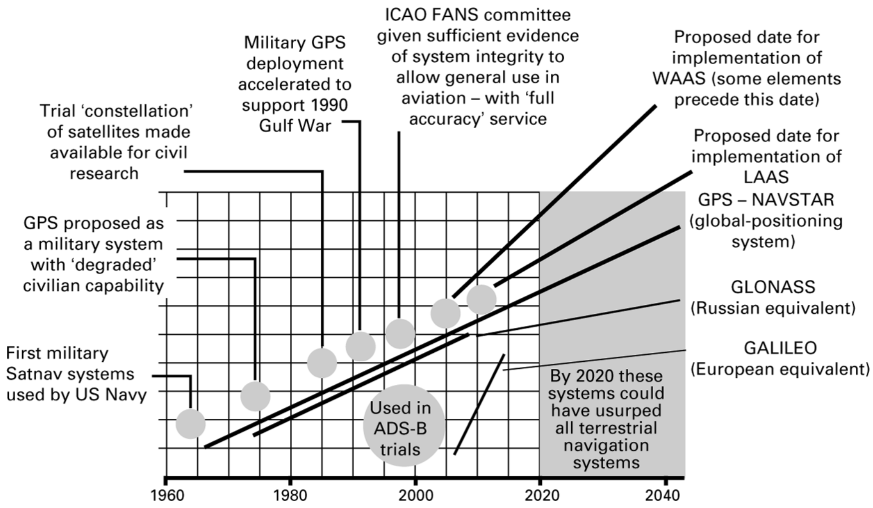
Omega was a codename that was adopted as the system name. It was a worldwide system, created and run exclusively by the US Department of Defense (DoD), which evolved in the 1960s, saw its hey-day in the 1980s and was withdrawn from use before the end of the century. The system used very low-frequency (VLF) radio signals. These required massive transmitting antennas (because the wavelengths were several tens of kilometres) and were valuable to the military because of the so-called 'ground-wave' propagation that provided long-range coverage and permeated water, allowing the signal to be received by a covert nuclear-powered submarine while it was submerged. The receiving antenna was small and had aeronautical applications. In principle it used the same techniques as the R-Nav systems that have already been described – Loran and Decca. Instead of having a chain with a master and three slaves that would serve a region, Omega had nine transmitters that were sequenced in time, and instead of being land-line connected to synchronise their transmissions, they used an atomic clock. The system promised 5-nm position-fixing accuracy worldwide, and while over much of the Earth's surface this was bettered by a substantial margin, in some places the propagation was poor and system usage was fraught with difficulties. By the mid-1990s GPS (the next system) was available and could outperform Omega, so the DoD switched off the stations, rendering all Omega receivers useless. This action, alongside a continuing expression of intent to turn off Loran systems, has been behind the skeptical views on US DoD ownership of GPS.

The *global positioning system* (or just GPS) is an acronym that has been synonymous with the way that satellite navigation (satnav) has developed, but it was simply the first all-encompassing system (in that military-only systems such as Transit were around in the 1960s). There are other systems and more are coming. GPS (originally called Navstar) emerged from a series of US military satellite-navigation developments that started their opera-

tional life in the 1960s. It was expected to serve the military by the mid-1990s and its influence on civil operations was not overlooked, but its utility was diminished by the imposition of signal signatures that did not allow civil users to obtain the full benefits of GPS. It was said, in the late 1980s, that GPS would provide a 50% probability of position error of 5 metres in the military (precision) mode and 200 metres or better in the civil (coarse) mode. It needed a ‘constellation’ of 18 satellites, six spaced in three orbits with about a 12-hour orbital period to be fully operational, as a user has to be able to view at least four satellites at any point in time to determine the precise position (in three dimensions). As more and more satellites were inserted into orbit the system showed that it would live up to, or even surpass, its promised level of performance, although the satellite constellation grew from 18 to 24. Intrinsically, GPS is like Omega, in that the satellite transmissions are synchronised using an atomic clock, but this is not carried from place to place any more. Periodic monitoring is conducted on every satellite at very frequent intervals (a few hours apart) and the receiver determines position by interpreting the time relationship of incoming radio pulses. The legacy of Loran and Decca, through Omega, hence lives on.

Conflict in the Middle East in late-1990 led to an acceleration of deployment and the military commanders were so keen to equip ground vehicles and troops that civil receivers were used, so for a while the precision code was accessible to civilian users. At about the same time, the ICAO Future Air Navigation Systems (FANS) panel published its vision of the attributes of a future navigation system and GPS was able to meet all the criteria, with one exception. There was no assurance from the US military authorities that the system had the ‘integrity’ that was needed. If it experienced a failure, and many kinds of failures could be postulated, would there be palliatives to protect users? Above all, in the event of conflict, would the US turn off the GPS system? In the early 1990s the US DoD submitted its own failure case analyses to ICAO, which hinged largely on describing the, until then, highly classified way in which the monitoring of satellite performance was conducted. These were assurances that silenced the critics. They had, by then, also announced two significant GPS-related system developments, called the wide-area augmentation system (WAAS) and the local-area augmentation system (LAAS).

These two systems were designed to allow civil users to obtain more precise position measurement from the satellite navigation system. An application that had emerged already was called differential-GPS (D-GPS) and was designed principally for surveyors. If a GPS receiver was located at a known position, it would derive position from GPS and thus derive also a measure of the GPS error. If that was replicated in the area, then applying that error to all GPS position data would provide the precise position. The WAAS concept envisaged doing this in a manner that would allow the error



4.5 Stages in the evolution of satellite-based navigation systems.

data to be communicated by radio data-link. (It is necessary to measure the error from different combinations of satellites and to provide a tabulation of errors so that a user can correlate position with the appropriate satellite combination.) WAAS was put into trial in the late 1990s, certification was expected to be straightforward and LAAS was slated to be approved in time for full use in 2010. The latter system was almost airport-based and was so precise that it could do the job expected of the MLS, thus causing the loss of interest in the earlier system. In the event, WAAS certification was much more difficult than anticipated and the programme has slipped. However, WAAS precision is so good that there is a strong feeling that LAAS will not be necessary. This is still not confirmed.

For stages in the evolution of satellite-based navigation systems see Fig. 4.5.

The US took the lead in satellite navigation (Satnav) and the rest of the world was not willing to watch or to depend on them. The Soviet Union started a project called *Glonass* in the 1980s. This has been sustained, albeit with less tempo, by Russia, and provides satellite navigation from an independent source. Europe has opted to develop a third system, called *Galileo*, which will become operational towards the end of the current decade (by 2010) as satellites are launched, often several at a time. (It was discovered recently that they are often using Russian rockets.) There is a Chinese system in prospect as well.

By now, there is a comprehensive set of Satnav systems, all able to meet ICAO criteria in terms of availability, accuracy and integrity. It seems likely that this will be the case for the foreseeable future and question marks are

therefore placed over the future of all the systems already described. Will NDB, VOR, DME, ILS and MLS all succumb to the superiority of a set of Satnav systems? These super-accurate systems offer the same fidelity almost anywhere on the Earth's surface – whether over oceans or deserts, or near the physical or magnetic poles. In all locations high-accuracy position-fixing is almost guaranteed. Within the organisations that supply navigation data to civil aviation, this is the big question. It has crept up on the industry so suddenly that it is still, metaphorically, in the process of taking a deep breath. Much of what follows in subsequent chapters outlines what the industry has to evaluate.

Navigation is a broad area to describe. The narrative so far has looked at the lessons learned from the rise and fall of many systems that have been in service and then withdrawn, with system extinctions peaking as the GPS began to show its capability in the last decade or so. However, a set of more autonomous – non-radio – systems has been and continues to be used widely. There is little evidence that their usage will diminish and some theoreticians think they could be more numerous than ever in the future. Their story requires a brief entry at this stage.

The *inertial navigation system* (INS) was devised by the military in the 1950s, initially to steer guided missiles, and then it was adapted for manned aircraft use. It was selected because it is an autonomous system and thus neither emits signals nor depends on radio emissions. It was first used on airlines in the late 1960s and was the standard navigation system on all long-haul aircraft in production within a mere five years. It used a gyro-stabilised platform on which was mounted a set of accelerometers. Before take-off the accelerometers were aligned north/south, east/west and vertically, and the latitude and longitude of a reference point at the departure airfield was entered into the system's computer. As the aircraft flew its route, the system monitored accelerations along each of the three axes and a computer converted these (a double-integral in mathematical terms) into distance covered, doing so with sufficient accuracy to surpass the performance of any human navigator. The equipment was expensive, but from that day on the navigator's days on long-range airliners were numbered. In general, system navigation errors, which grew with time, were around 0.5 to 1.0 naut. miles per hour. At the end of a trans-Atlantic crossing an INS set could deliver an aircraft to a point which, with a high probability, was within the destination airport boundary fence.

The *laser INS* (LINS) is a logical development of the INS, as in this device the mechanical gyroscopic stabilization is replaced by solid-state laser ring gyro (LRG) units. The system now operates with no moving parts, so it has improved reliability and is even cheaper than the INS to own and operate. Nowadays airlines often have combined LINS/GPS sets. The reason for combining these two navigation systems is that they have dissimilar failure

modes and error characteristics, so each complements the other very well. (This is an example of a 'systems' solution where it can be argued that 'the whole is greater than the two halves', but more about these later.)

Note that on a long-haul aircraft one might expect to find three such units, which are all cross-monitored. Thus the failure of any one is recognisable, so it can be disconnected, and the aircraft can continue on its way without any significant impact on the level of attainable safety. This accords with the failure-case criteria that are exemplified in the risk assessment part of safety regulation in Chapter 3.

Summarising the current navigation system situation soon reveals that this is a turning point in the history of the subject. That is true in aviation as well as in many other sectors, such as transportation, surveying, time-tabling/scheduling where Satnav has poked its fingers and won first place over all comers. If this author feels challenged, especially in the breadth of issues that are being addressed in this review of the air transport system, it is in knowing where to cast the net in regard to where Satnav will influence solutions to forthcoming system issues. Within this section itself, when commercial operational infrastructure is discussed, do not be surprised to find that the eponymous Satnav systems work their way into the debate again and again.

It is time to consider the third, and final, element of CNS systems.

4.3.3 Surveillance

A *radar* or *'primary' radar* (to distinguish it from a *secondary surveillance radar* (SSR), which follows) is a radio-detection device, the principles of which were proven in the late 1930s. There are many kinds of 'radar', all used in aviation – weather radar, interception radar, height-finding radar, etc. – but in respect of the air transport system, only ground-based surveillance radar will be considered. Radar is a 'line of sight' system (roughly) that detects objects in the area swept by its narrow, rotating, beam by detecting reflected electromagnetic energy. The bearing of an object is determined from the beam position and the range is determined by the time taken for energy to return to the radar station. An ATC surveillance radar will typically detect airliners from 20 to 150 naut. mile maximum range, the absolute range being determined by the power transmitted and the application for which the radar is employed.

Throughout development from the 1960s radar has been integrated with the digital computer, in what is often called a radar data-processing (RDP) system. This is a way of extracting position from a radar, or a set of radars, and of developing each return into a 'plot' that can be shown at a position on a display system. (The circular 'rotating strobe' form of display is not nearly as common in ATC workplaces as it is in movie renditions.)

The *secondary surveillance radar* (SSR) was introduced in Section 4.3.1 on communications, as it is the ground element of the ATC transponder. The ground-based interrogator, which is mounted on a radar-like rotating structure (and will often be mounted on the same 'head' as a primary radar), emits pairs of pulses that trigger a 12-pulse Mode A (code) or Mode C (altitude) response from the aircraft's transponder.

Mode A is a four-number code, each number having a value from 0 to 7 only; thus 0000 is the lowest and 7777 is the highest numerical value that can be transmitted by an aircraft. There are 4096 possible combinations in total. The aircraft crew can set the code on a flight-deck panel and will be allocated a code (called a 'squawk') by the ATC.

Mode C uses the same 4096 code system as Mode A, but the 'framing' pulses are at a different time separation and the pulses this time are created from an encoder on the aircraft altimeter, such that the transponder conveys the altimeter reading to the interrogator on the ground.

Mode S interrogation and transponder systems are a third version of SSR and are in the process of being commissioned. These will allow up to 128 bits of information to be exchanged both ways between the ground and aircraft, which will almost certainly be the preferred digital data-link system for ATC service providers in the near future. A Mode S compatible transponder is already mandatory for all commercial aircraft, in virtually all controlled airspace, throughout much of the world.

The SSR uses similar codes and frequencies to the military Identification Friend or Foe (IFF) system. This accounts for the missing Mode B and is why the SSR is sometimes referred to as the IFF. Aircraft nowadays have an on-board low-power ATC transponder interrogator that will trigger responses from nearby aircraft. This is the primary information sensor for the TCAS, a system that will be encountered later.

Autonomous dependent surveillance (ADS) has already been mentioned in Section 4.3.1 on communications as it is really a communication link, but the information it will convey includes aircraft position, so when it carries this information it is effectively a surveillance (position-detecting) device. Trials commenced in the late 1990s and it is anticipated that the system will quickly be accepted as the prime source of position information for aircraft that are flying over oceans and unpopulated areas; it could also become the primary communication device overall in the fullness of time.

As the summary presented in Section 4.3.1 on communications showed, there is some doubt as to whether ADS or the Mode S transponder will be the preferred data-link solution of the future. Mode S requires a ground station and it will almost certainly dominate in certain regions. ADS, however, is available worldwide and will dominate over oceans and sparsely populated areas. Hence, the final solution might almost certainly be a combination of ADS and Mode S. By having a combination, there is less

likelihood of a common failure causing total communication system breakdown. This is repeating the story presented in the case of INS/GPS and upholds the safety case risk-assessment techniques discussed in Chapter 3. Systemic solutions appear through such justification. They have to be justifiable – they cannot arise simply from an idea.

4.4 The airborne elements

The CNS system elements already described have done much to stimulate change on the airliner flight deck – so much so that pilots whose careers spanned the 1940s to the 1970s saw tremendous change. In that period, the typical crew complement fell from five to three, and the systems they operated were often radically different. Since around 1982, when the first two-place flight deck rolled from a production line the overall configuration has changed little, but the roles performed by the crew members have changed a great deal. In the future, the changes could be even more radical, because while aircrew were once virtually as remote as desert-island stranded survivors, nowadays they can be bombarded with communications. Aircrews are aware of the changes that will occur and keen to ensure that safety-consciousness is maintained. They look towards the flight deck of the future where a crew will be genuinely assisted, not just monitored, as they accept an ever-increasing heap of responsibilities.

In reviewing flight deck developments a roughly chronological approach is used to guide the narrative, respecting how technology, needs and implementations coincided. The aim is to provide a key to understanding how the developments currently being revealed can be expected to impact air operations in the future.

Up to about 1960 avionic systems were developed by specialist companies, each developing a saleable product that was self-contained. The aircraft was offered to a customer (airline), who was free to specify the majority of equipment to be installed. This meant that few systems connected at any stage with any other system. Each supplier bought-in or built their own sensors, developed electronic processing units (usually analogue technology) and also manufactured small control panels, as well as their own instruments. Because they were customised to the customer's needs, the systems were expensive to maintain. The typical flight deck was 'cluttered' and human–machine interface issues (as accident reports from that era testify) plagued operations.

If an airline bought a second-hand aircraft, although externally the aircraft might look identical to other examples already owned, it was inevitable that the systems would be very different. The cost of re-equipping aircraft was excessive, which was one reason why aircraft were often

scrapped after only a few years in service. Airlines appreciated that 'standardisation' would bring several benefits, such as:

- common installation from different manufacturers, which meant that customers had greater choice and the better supplier could usurp less capable competitors
- by corollary, the manufacturers had to offer better value for money
- systems could exchange information (because the interfaces were standardised)
- common installation standards led to simplified production, meaning that costs were reduced.

These are system attributes that happen to meet financial, safety, efficiency and effectiveness criteria.

Standard-sized instruments and standard-sized processing units (by now called avionics) allowed installations and data interfaces to be defined precisely. This meant that if a supplier went out of business, their equipment could be replaced by another supplier's equipment, or data could be exchanged or integrated within display units, thus reducing flight deck 'clutter'. The commonality standards were addressed as 'form, fit and function' compatibilities.

Flight deck layouts evolved with a more regular set of instruments and control panels, often hiding the fact that the aircraft systems controls were still complex and needed to be continuously monitored. Therefore, while the radio operator and the navigation functions were eliminated, for a number of years a flight engineer sat behind the two pilots.

The surge in advancements that has been attributed to 'generations' of technology took a significant leap when, around 1970, digital electronics began to replace analogue devices. At this point very deliberate 'integration' began and the most notable development was the data-bus, which is a very high capacity digital data-transfer system. Systems could use the same, or a set of common specification, data-transfer systems, and thus any information from any unit could be made available to any processing unit, any processed data were available for any display system, and so on. The companies making 'instruments' or 'radios' in the 1950s had become systems integrators by the 1970s. The major principles of business were also upheld:

- These devices led to lower cost of ownership (although they were more expensive to buy, they needed one less crew member, as the flight engineer now disappeared).
- They were intrinsically safer, in that information could be shared and disparities almost eliminated (but this was a trend that had to be applied judiciously).

- They used processing capability efficiently.
- They offered ease of operation and cost benefits that the users wanted.

The most important issue at stake was the fear that one failure, or an inadvertent misuse, would have a catastrophic effect on operational capability. The reduction of the possibility of such an instance, to the point that it becomes an 'acceptable' failure in risk assessment terms, is essential in systems design and development work. Much of significance has happened that is non-CNS related. For example, fuel and 'utilities' management systems and automated flight control systems (AFCS) – at one time the humble 'autopilot' – have all witnessed changes in their configurations that have had an impact on the crew interfaces. Indeed, overall, the crew interface on a modern flight deck has been trusted to a diminishing number of highly integrated systems, such as:

- the automatic flight control system (AFCS)
- the flight management systems (FMS)
- the electronic flight instrumentation systems (EFIS) and
- the electronic centralised aircraft monitoring (ECAM) or engine instrumentation and centralised aircraft system (EICAS).

New sensor systems have contributed greatly to safety, especially in a workplace, where the time that can be devoted to monitoring has been diminished. These have included:

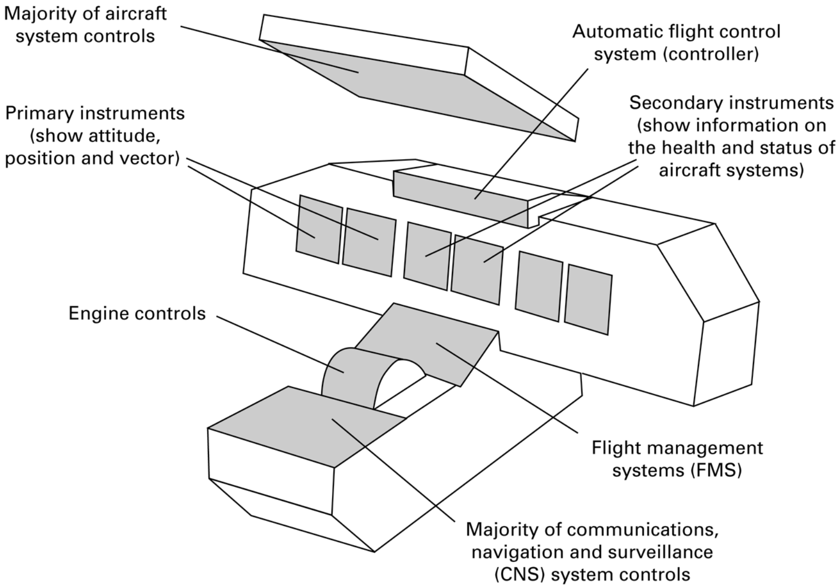
- ground-proximity warning systems (GPWS)
- the later enhanced GPWS (EGPWS)
- traffic conflict-alerting system (TCAS) and
- radio-based data-links, such as Mode S transponders and autonomous dependent surveillance (ADS).

In the next few pages a review of these devices is presented. There is no apology that the actual operation of these complex devices is not delved into at button and indicator level. The aim is to present a clear impression of what can be achieved when integration is not just preached but is practised.

The issues that spurred these advancements were entirely in tune with the creed already espoused, that cost-effectiveness, safety and efficient operational outcomes were the essential drivers. A point to stress is that this is a race that began as described here and that it is still not fully run. A schematic of a modern flight deck is shown is Fig. 4.6.

4.4.1 Automatic flight control system

The automatic flight control system (AFCS) grew from the so-called 'autopilot' (affectionately called 'George'), which was installed in long-



4.6 Where to find what on the modern flight deck.

endurance military bombers. The device would hold a steady course and sometimes a steady altitude, thus relieving the crew of the need to maintain control throughout long periods of cruising flight. The 'civilianised' equivalent – indeed, a few civil aircraft had crude autopilots before their military application – allowed a crew to 'dial-in' heading, altitude, rate of climb/descent and, when engine control was added, aircraft speed. What intensive usage in military operations had revealed was that the system needed to be monitored by the crew, as it was a safety-critical system with major, and sometimes potentially hazardous, failure modes.

Post-1945 AFCS designs had expanded capabilities and came with a combined instrumentation package with a flight director (FD) system, which added mechanical symbology to the artificial horizon instrument, placed 'bugs' on the airspeed indicator and compass displays that showed selected values, and so on. Within the AFCS/FD manufacturing community different 'styles' of display and control evolved, although the principles were all similar. By the time jet-powered airliners were entering service the AFCS (still called autopilot in some references, but this term has been relegated since to describe simpler systems) was already integrated with the radio navaids, such as VOR and ILS, and later DME, so that a course could be selected and flown with the system taking care of cross-wind drift. The time-to-go to waypoints was easier for a crew to compute as they could monitor the situation all the time.

There was a price to pay; as the systems became so crucial to achieving

daily service reliability targets and for moderating the crew workload after the navigator and radio engineer had been automated off the flight-deck most AFCS installations had two channels. They would be monitored independently by the two pilots and discrepancies used to detect 'failures'. This did not deter manufacturers from including built-in test (BIT) systems, and if these issued a warning before the crew had detected an error, the warning often assisted a crew to decide which channel they should trust. They had plenty of other monitoring options and a competent crew could detect unacceptable AFCS performance (a gentle 'runaway' was the most insidious, when an attitude or flight-trajectory datum began to change imperceptibly and was only detectable after a sizeable error had been achieved). The AFCS thus became cemented into the jet airliner flight deck. Around the 1960s its controls were usually in the centre console, just behind the throttle levers, but as the system's usage grew in importance the controls were developed as an elongated control panel that could sit on the centre coaming, where it occupied a spot that for decades had been devoted to engine fire indicators and extinguisher controls. The engines were now more reliable and the AFCS was important enough to take this prime spot.

The most capable AFCS systems became multiplexed, with triple or quadruple channel configurations. Whereas earlier systems had been able to fly an aircraft down the approach, with the crew hands-off until decision height, the newer systems could be trusted to perform an automatic landing. This was not just engineering bravado. This was a capability that could assure an airline of service reliability in almost any low-visibility weather conditions (which in the 1960s were becoming embarrassingly commonplace). The systems included self-monitoring, usually with 'majority-vote' concept comparators, and thus a three-channel system could survive a single-channel failure. The four-channel systems used were so-called 'duo-duplex' with equivalent failure-survival modes. These systems, using ILS (or more lately GPS) guidance, with a radio altimeter to assess height, allowed fully automatic landings to take place in even the most severe conditions of low cloudbase and visibility. The so-called Category 3 (Cat 3) system, which needed equivalent failure-survivability built into the ground-based radio guidance system and astonishingly complex aerodrome lighting systems (described in Chapter 7) will allow a crew to land with a zero-foot decision height (DH) and in visibility conditions, expressed as runway visual range (RVR) conditions, below 300 metres to as low as 75 metres.

Most AFCS technology was developed using analogue computing and the basic concepts remained unchanged, but the implementation changed radically as the digital electronic generation emerged. Whereas separate roll, pitch and yaw 'channels' were built into each control channel in the analogue era, in the digital computer these could be handled by time-slicing, or time-sharing, the computing element in a single channel. The AFCS

became lighter and the individual units within the system tended to become more reliable. The biggest drawback of the 1970s designs was that the flight director system, which had attitude director indicator (ADI) – in effect a complex artificial horizon – and horizontal situation indicator (HSI) components that were still electromechanical, could fail to display what was being detected within the system.

In terms of the human–machine interface, the displays that are used by a crew have to be as effective as the controls at their disposal. A stunning failure example of the era was the catastrophic failure of the liquid oxygen tank on the Apollo 13 lunar space mission, which so nearly led to the loss of the crew. The system that failed had been damaged, and subsequently repaired, after it had overheated many weeks before it was launched, but because the temperature sensor recorded only up to the highest *expected* normal temperature value, the severity of the event had been unrecorded and went unnoticed. Within the system the damage was substantial, but that was not evident until failure occurred.

There are many equivalent examples in civil aircraft operations of instances where crews have been given erroneous, or misleading, sensor information that has not been recognised, and has been irrelevant in operations in general, but has become the most critical seed at the root of a chain of events that have led to a disaster.

4.4.2 Performance management systems

Performance management systems (PMS) formed a transitory unit, but it set a precedent that deserves a mention. A crew could deduce, but often could not articulate because they lacked the time needed to consider, how wind, air temperature, aircraft mass and other variables would influence performance. The PMS was a computer that was hooked into the appropriate aircraft sensors and could carry out performance calculations at the touch of a button. It could advise a crew when to request an altitude change, assess the fuel penalty of a non-optimal cruise clearance, and so on. The firms that developed these systems were often small companies, aware of new opportunities, and they were galvanised to offer a worthwhile development to aircraft operators when the fuel crisis of 1973 bit deep into the financial performance of many airlines. Their devices were not universally accepted, however, as they were expensive to install (needing so much linking to many sensors) and difficult to incorporate in any aircraft. The PMS supplier also faced difficulties because almost every aircraft had systems that differed subtly from each other in certain ways. Each aircraft installation was a major integration task, with different implementations applied across similar aircraft types that were used by different operators. Systems integration was a major headache and those who had bitten the

challenging bullet that PMS represented were often bankrupt before they had started to deliver the product, because they had, unsuspectingly, entered a minefield. A lucky few were absorbed, through mergers and takeovers, into larger firms, and some really talented entrepreneurs shifted their gaze to the less susceptible business-jet and general aviation markets, and succeeded quietly in that field. It pays to be brave occasionally, but the risk in a commercial sense is often more hazardous to affirm than the technical risk.

The solution to the integration problems was the data-bus, which had been introduced around 1970 (the Boeing 747 being the first aircraft to use the Arinc 429 data-bus system from its service entry date). Even though it was a very lack-lustre system, in terms of operating capacity, it was the major system for 'standardisation'. Its limitations were largely because regulators were risk-averse and stuck to an implementation that was achievable using mid-1960s electronics technology. It was not an unwise decision, but their choice was under scrutiny and faced criticism at the time. This is indicative of the dilemmas that face a designer in a high-technology industry where the working parameters are moving rapidly. Arinc 429 was a 20 000 bits per second specification, drafted in the late 1960s. It assumed the use of 32-bit digital 'words' and thus could convey around 500 words per second. It offered terrific performance in its era, but by 1973, when Arinc was reviewing all equipment specifications to harmonise data interfaces, it did not go unnoticed that the US military had adopted a data-bus technology, called Mil-Std-1553, that achieved 1 million bits per second and used 16-bit 'words', thus intrinsically offering over 50 000 words per second. Nowadays even these rates are regarded as 'pedestrian' in widely available commercial products such as multi-user computer games, and no doubt the rise in 'bandwidth' in such applications has much more yet to offer.

Nevertheless, the die was cast and from the mid-1970s commercial aircraft systems were being designed to make best use of this 500 word per second technology. The digital flight deck would be radically different to that of previous-generation aircraft, largely on account of three developments:

- electronic monitoring and control of on-board aircraft systems
- electronic displays (replacing the electromechanical displays)
- the flight management system (FMS), which usurped PMS.

A consequence of these changes was the ability to design an airliner with such well-harmonised display and control interfaces to the crew that the flight engineer was no longer needed. The two-place crew compartment was heralded by Boeing on the 757 and 767 airliners and on the Airbus A310. They were based on the same equipment specifications (Arinc 700 series) and by offering three aircraft types with almost commonality of all sensors and many control and display components, these airliners allowed the equipment manufacturers to see a financially sustainable product develop-

ment programme. The sheer scale of the development of these systems was daunting to some firms and in the end only a handful of them, almost all conglomerated in some way, have survived to develop modern aircraft systems today.

A brief account of the attributes of the main systems is given below.

4.4.3 Electronic control and monitoring or engine instrumentation and central automated systems

This system manifested its presence on the new aircraft as electronic cathode-ray tube (CRT) display screens in the centre of the main instrument panel. The screens provided information and enabled a crew to monitor systems. This meant that what had occupied a sizeable amount of space on the flight engineer's panel in the rear of the flight deck on previous aircraft types was compressed to two screens that were relatively small. The system did this by having 'multi-function' screens, with 'pages' devoted to systems, such as fuel, electrics, hydraulics and environmental control. If all was well, the pages would be blank. In the most common implementation the 'default' screen shows engine instrumentation data, and in recent times the CRTs have been superseded by liquid crystal display (LCD) units, which are lighter and more reliable.

Behind the displays a computing element takes in all the systems data (not always on Arinc 429 interfaces) and compares, using software, the value of each parameter with a scale that categorises it as green, amber or red, for okay, of concern and out of range respectively. The computer is doing what the flight engineer used to do. If the results are green, the system display shows nothing, but if a warning is appropriate the system can activate an attention-getting annunciation (usually on a small panel adjacent to the ADI and thus within each crewman's primary field of view) and the display 'page' for that is shown immediately. The parameter values are colour-coded, so unacceptable values can be seen immediately by the crew, who exercise control via control units on the overhead panel. These are arranged in a schematic diagram fashion and the lights that display the status of control effectors (pumps, valves, switches, etc.) are arranged to illuminate only if they need the crew's attention. Getting all of this into such a small space and leaving the crew free to make decisions and take actions with confidence about the outcomes has been paramount to making the transition from three-place to two-place flight deck design. Of course, this achievement has also contributed to reducing the operating cost of aircraft.

4.4.4 Electronic flight information systems

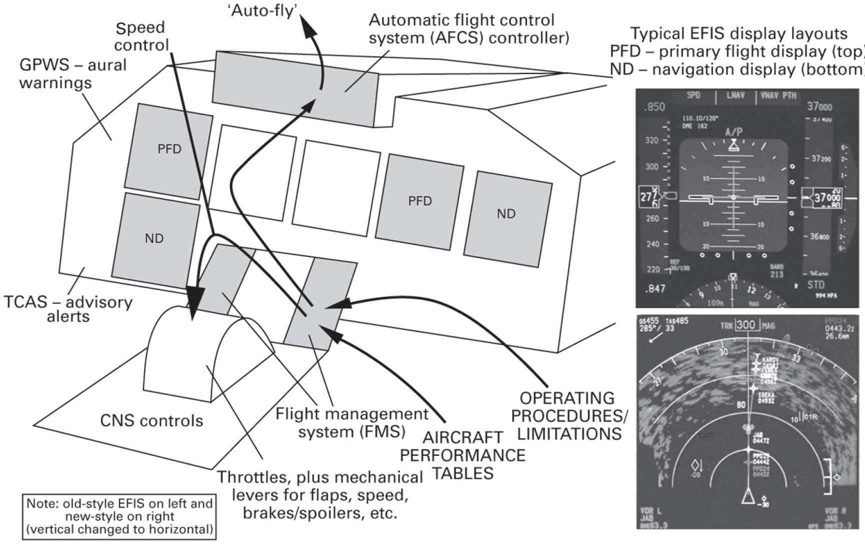
This system is at the 'heart' of the new airliners. An electronic flight information system (EFIS) nowadays comprises liquid crystal displays (LCDs) on which primary flight, navigation and systems data are shown to the crew. There are usually two display screens per crew member and they take over from the mechanical attitude director and horizontal situation instruments (ADI and HSI). They do much more than simply present the original instrument data in electronic form and have become known as primary flight display and navigation display (PFD and ND) respectively. Compared to their predecessor instruments, these are superior displays in respect of reliability and legibility. Circular needle-based pointer instruments have been consigned to history, although it is interesting that many of the display characteristics of old instruments are retained on electronic displays, because the human eye has a strong affinity to 'pattern recognition' and in the subconscious the human mind will 'read' the rate of change of a variable from the motion of a dial-mounted needle. The flight deck changes were often achieved with little need for well-practised crews to learn new ways of assimilating information and in that regard the potential impact of change on safety performance was minimised.

4.4.5 Flight management system

This was the third of the three highly integrated systems that first saw the light of day around 1982. A flight management system (FMS) is a computer on board the aircraft that, in addition to incorporating all the 'software' of the PMS, has electronic memory that stores navigation aid and airport databases, the flight plan (in fact, many flight plans, of which the one of current interest only might be selected) and the airline's operating procedures.

When the crew is commencing a flight they declare departure and destination points (or a flight code), and the system will retrieve the flight plan. It will request or deduce aircraft data (such as payload and fuel load) and weather information, such as the wind forecast, and create a real-time flight plan that will forecast time en route, taking account of ground speed and air temperature variations, etc. The PMS-related core of the system will instruct the crew which level/speed combination will make for the best economic performance. It will also set up navigation and communication receiver sets, re-tuning the units as the flight proceeds, and so on. Throughout a flight it will be computing navigational data and presenting to the crew such information as time to go, distance to go, top of descent, etc.

The FMS can also be linked directly to the AFCS. On departure, when



4.7 Aircraft information handling.

told to fly a certain route, the FMS will obey all the built-in characteristics of the procedures in terms of minimum/maximum speeds, altitude/level clearances at waypoints, etc., and can be used to steer the aircraft, fully automatically, from a point soon after take-off to the point where it is stationary at the end of the landing roll.

The FMS is a small unit, usually located just ahead of the throttles, one on either side of the centre console. On its face there is a complete alpha-numerical keypad, a small number of dedicated 'function' keys and a six-line electronic display. It looks inconspicuous, but it is a vital piece of equipment.

The above were all 'integrated', in that they used common interfaces and were fully compatible when different suppliers were selected to supply different parts of the complete system for an aircraft. Figure 4.7 adds a pictorial aspect to this. Alongside them, stand-alone systems developed, and have proved their worth in many ways. These devices are dealt with next.

4.4.6 Ground proximity warning system

The ground proximity warning system (GPWS) was a microprocessor-based system, developed as soon as the technology was available (early 1970s) and tailored to assist a crew who had inadequate spatial awareness to appreciate that they were in a position that was perilous. In safety requirement terms it

was designed to recognise a set of circumstances that were potentially 'major' in terms of a safety effect and to provide the guidance necessary to alleviate the situation. The situation of concern was controlled flight into terrain (CFIT). The unit simply took radio altimeter data and barometric altimeter data from the appropriate data-bus lines (thus it was very easy to install) and detected unacceptable combinations of the height above terrain and the terrain closure rate, issuing a verbal 'whoop, whoop, pull up!' warning. The device would detect when an aircraft was descending close to terrain and even when an aircraft was level and the terrain was rising beneath the aircraft.

The primary terrain-protection 'modes' were soon supplemented with additional modes that monitored glideslope deviations – shouting 'glideslope, glideslope' – and even detected the rare, but potentially catastrophic, instance of when an aircraft would begin to descend after take-off, owing to circumstances such as retracting the flaps at a low speed, in which case the system call was 'don't sink!' After its introduction as a mandatory system in commercial aircraft in the late 1970s, the incidence of CFIT events reduced dramatically. It was claimed that it cost less than a new aircraft paint scheme and yet would save lives.

4.4.7 Enhanced ground proximity warning system

GPWS was not able to see 'ahead'; it was a device with efficiency limited by the fact that it used the radio altimeter, which looked downwards. As mass-memory devices became available the GPWS was linked to an electronic elevation map, which became available because satellite-based radars had mapped the Earth's surface to a consistent level of accuracy throughout the 1970s and 1980s. The system could now detect if the terrain was above the aircraft, in the near region and whether the rising ground that was about to trigger a warning was in fact a terrain feature that would soon flatten off and not be an impediment to the aircraft's progress. This alleviated a lot of 'false warnings', which had plagued GPWS operations in very difficult terrain, and the new system became widely available in the 1990s.

In addition to producing a verbal warning the enhanced GPWS (EGPWS) could 'draw' terrain on the navigation display, so the crew could see the contours of nearby mountains as they descended into valleys. The visual reference was compelling and good, provided the software was reliable. As these notes are written the certification of 'synthetic vision' that takes this display technique a stage further is taking place.

4.4.8 Terrain awareness warning system

The terrain awareness warning system (TAWS) is a standard-fit item on the latest generations of airliners. In addition to providing a plan view of terrain (usually as contour patches that turn amber and red if minimum height criteria are breached), TAWS draws the terrain ahead of the aircraft (contributing to 'synthetic vision') and an illustration of the profile under the intended flight path, which is comparable with terrain drawings used on instrument approach charts. This needs FMS assistance and the display is integrated into the EFIS ND. This might be the final nail in the coffin of the voluminous loose-leaf flight guides that pilots have long had to carry and update periodically. The advent of an electronic library was heralded in the late 1990s and the fact that Boeing purchased outright one of the major suppliers of charts in later years almost cemented this development as a certainty. Expect safety regulators to crawl over the manual 'updating' procedures, cognizant that a failure to supply accurate data will be potentially catastrophic in electronic flight deck operations.

These were far-fetched ideas barely a decade ago. Aircrew flight bag manufacturers can expect demand for their product to diminish and 'posers' with such accessories should be aware that they will be 'old-fashioned' if they do not change their ways. For a decade or two it might be the biggest differentiator between the 'haves' and the 'have nots' of the flight deck community.

4.4.9 Traffic collision-avoidance system

As the world's airspace became more crowded there was one horrifying prospect, and that was the chance of a mid-air collision with another airliner. The possibility existed from the first day that two aircraft were airborne simultaneously and as traffic levels rose, sadly, the opportunity increased and the record of such events rose too. Sometimes this took the form of an unequal encounter, with a light aircraft smashed by an airliner. While the dented airliner and its shaken occupants survived, the light aircraft occupants became aviation fatality statistics. However, this was not inevitably the case, as an airliner struck in a way that it suffers a catastrophic failure leads to huge loss of life. Airliner-on-airliner collisions were rare, but as high-accuracy navigation systems have become commonplace, the incident rate is increasing and the outcome is most certainly related to the cause. Of course, the ATC system, through its separation criteria, should render such a possibility as acceptably small. The risk assessment of such cases is one thing, but the way that circumstances have conspired to create the 'loopholes' that accident analyses have revealed has

left no one in the safety community in doubt that an on-board collision-avoidance system is vital for future operations.

In fact, research in this field was underway over 30 years ago. Thoughts turned to putting radars on airliners, but it was impractical (because airborne radars – as used in military fighters – are heavy, expensive and not very reliable) and the field-of-view of a radar is limited. If the latter problem was addressed in the manner employed for airborne early warning (AEW) aircraft, the solution was more than one radar or a radar mounted within a rotating radome. The same impracticality was signalled. What did emerge was very novel and has proved to be very successful.

The traffic collision-avoidance system (TCAS) is a device that uses a low-power ATC transponder interrogator on the aircraft to measure the distance and relative height of aircraft nearby. If it determines an unacceptable combination of range and range–range, and relative height, it will present an avoidance instruction on the aircraft instrumentation. The TCAS has been mandatory on almost all public transport use aircraft since the early 1990s. It employs a weak interrogator unit and a receiver that can assess responses from aircraft nearby (within 35 km or so). The actual range and the rate-of-change of range (range rate) are measured, and from Mode C responses the aircraft relative heights are assessed. If the aircraft are vertically separated by at least 1000 ft and are not climbing or descending towards one another, their responses are ignored. Likewise if the range rate is increasing (meaning the distance between the aircraft is increasing) the responses are ignored. In all other cases, if the range rate and range information suggest that the aircraft are within a 'trigger interval' (about 25 seconds), the TCAS will create a warning to the crews of both aircraft. The responses are coordinated to ensure one is told to pull up and the other to descend.

At first this system was frowned upon by air traffic control (ATC), whose natural reaction was to see it as a device that would question their own judgement with regard to separation criteria, but also because it seemed to put 'control' into the aircrew's hands. Aircrews, given the system added to their awareness of the traffic situation around them, were more enthusiastic. The TCAS started off as a unit with a dedicated display and then it became a display that combined the conflict resolution information with the vertical speed indicator (VSI). Nowadays, it is even possible to consider determining the precise location of other aircraft in the vicinity, whether they are a hazard or not, and to show them on the plan position layout of the EFIS ND. Most systems will do this adequately well, except that when an aircraft is manoeuvring and thus changing its datum, this is not always an advisable way of using the system. ADS might be the 'integratable' sensor that will override that situation, however.

An unrelated development that has led to the TCAS being invaluable is that as aircraft have gained access to very accurate navigation data, the

degree to which they wander about a nominal course is much less than hitherto, and this excellent performance has the side-effect of meaning that two aircraft that are unmonitored, but following the same procedure, face the prospect of not just becoming ‘too close’ but of being guided towards a collision. The TCAS could not have emerged at a better time – and one reason it did is because some researchers had the foresight to see this rather doom-laden justification in their own assessments of emerging operational realities.

4.5 Future trends

The changes that have been charted in the operational environment have been continuous and the rate of change has not appeared to diminish over time. The advent of digital computers, in terms of the capability they bring to sifting, classifying and presenting information, is an area where the potential impact possibly has much further to run than can be surmised from a review of history and a simple extrapolation of current trends. The scientists and engineers are as sightless on these aspects as traffic forecasters working at the commercial end of the industry.

In recent times the head-up display (HUD), which has graced high-performance military cockpit coamings for 30 years or so, is likely to arrive on the commercial flight deck. This was not an apparent development even 10 years ago, because it seemed too expensive a device to justify. However, rapid development of new display technologies – much of it fuelled by display-transmission expansion in public broadcasting – has triggered technologies that are working into aviation.

The most important point to bear in mind is that changes arise for reasons. The causes are not always technology driven and with the way that the air transport system is beginning to evolve, with a wider sphere of concern of subjects including the covert impact of aviation on communities, it is almost inevitable that CNS and airliner systems of the future will be tailored to respect these wider perspectives. The challenge is to identify how these perspectives will emerge and what changes they will want. That challenge will be explored in later chapters.

5
Aircraft

Abstract: In this chapter the airliner manufacturing commercial and technical viewpoints are combined, within contexts that allow them to be interrelated. There is a systemic approach, starting with a view of each airliner as a project and outlining the lifecycle-related issues that influence commercial cost and risk. The latter is related to technical choices, which are assessed in terms of the options they deliver to a manufacturer. The influence of requirements, borne of the demand for services and the need to be efficient, plus the requirements that reflect customer expectations are grouped under an effectiveness heading, and are shown to influence a manufacturer's choices too.

Keywords: project cash-flow, infrastructure compatibility, aircraft operating costs, aircraft performance, customer service requirements.

5.1 Introduction

Aircraft are the most recognisable element of the air transport system. They are iconic within society and are, above all, the root of the solutions to any of the industry's 'pollution' problems. The understanding needed of airliners is of their value in commercial and service terms. There is no easy way of changing the course along which aviation technology is orientated. It can be deflected, but not changed abruptly, without grave economic consequences – on society, not just the air transport business. However, the manufacturers in turn are increasingly aware of how their products connect the natural and operational environments to the needs of the air transport system and the desires of society, both in the short term and the long term. Given that perfection is a witless aim, they seem sure to have a hard time at the hands of demands, which are influencing aviation through ideas of 'environmental' (flora and fauna perspectives implied) regulation. These horizons can be studied in depth when the relationships that shape the industry have been portrayed.

Some 22 000 turbine-powered airliners are in service worldwide. The number has grown at a relatively steady annual rate for many decades, and this trend is fuelled by passenger service demand that shows no signs of abating. In a typical year some 1000 new airliners will roll off the world's production lines. They will be used for about 20–25 years, by which time they are usually retired and scrapped. Airliners are worked hard and a well rehearsed motto is that, during its working life, an aircraft on the ground is an aircraft not earning money.

5.2 Costs

Aircraft are considerably more expensive in terms of cost per unit of mass than simpler items. For example, an airliner will cost between 800 and 400 US$/kg (note that all prices will be quoted in US dollars). Generally, the smaller the aircraft, the higher the cost per kg. (This is an evaluation based on the maximum permissible mass for operations.) Some example prices are quoted later in this chapter, in Table 5.2. As an example of how expensive an airliner is, if a family car that took to the road at 1.5 tonne maximum and was sold at an equivalent scale it would cost in the order of $750 000.

Banks and finance companies or, occasionally, airlines themselves finance the purchase of aircraft, and they must expect an aircraft's capital cost to be recovered during its operational life. As well as seeking to recover this initial cost, it has to be borne in mind that running and servicing an airliner incurs additional costs. Even a relatively small (150–200 seat) airliner can cost $50 million, and the largest of all reach the dizzy heights of a quarter of a billion (250 million) dollars. Look at an Airbus A380 and one is looking at a business, in its own right, that will need to generate about $2.5 to 3 million per week. The Boeing 747, which has already graced the skies for almost 40 years, is not far behind. These simplified examples illustrate that, within airlines, each airliner is often a respectable-sized business in its own right.

To begin understanding the modern airliner, it is important to consider the process through which it is created and what is involved, as this will also show why a manufacturer has to carry a commitment that they will be forecasting to fulfil needs for many years into the future. Their decision-making procedures do not allow them to change course very readily.

5.2.1 Project cash-flow

Those manufacturers who have tried to break the mould with regard to the variables involved inevitably have been ruled out of the business. Boeing continues a long-standing name, but on the way has subsumed Douglas, and at times has owned and operated other companies that it has sold on again. Airbus in Europe evolved from a consortium of European manufacturers.

Between them these two firms account for almost all airliner production in the 150-seat and above category, throughout the world. The Soviet Union seeded a small and in industrial terms an inefficient industry, and there are signs that one day soon its legacy might re-emerge, but it has been in Brazil and Canada where small airliner production, the so-called regional jets, has been handled successfully. There are signs that there will be an Asian challenger, perhaps in the Boeing and Airbus sector, that will emerge from China or India.

Consider what is involved, financially, in a modern airliner development and production programme. The A380 has been quoted to be a $10 billion investment by Airbus Industrie, and the company's commitment is reported to be much higher by some independent sources. In other words, Airbus has had to invest a vast sum to cover the cost of designing the aircraft, create facilities for its production, nurture numerous support roles (both technical and commercial/administrative), certificate it and to maintain a steady rate of production. If each aircraft costs, in round figures, $250 million per example, a simple comparison of the cost to create with the cost to customer might suggest that only 40 aircraft would generate sufficient revenue to recover costs.

The true figure almost certainly will be in the order of 250 aircraft, or $62.5 billion worth of production, before all attributable financial liabilities are paid off. Airbus suggest that the production rate will be around 4 aircraft per month, or 48 per year, so the production line will have to run, at its best capacity, for at least 5 years. However, before production deliveries can commence there is the full design and certification programme. Designing an airliner from project launch (and thus ignoring the cost of a lot of pre-launch research and development work) to when the first components can be fabricated is usually a number of years. Then there is a period when design and build activities overlap, leading up to the aircraft roll-out. In this period many of the facilities that will support production are built from scratch and novel processing techniques are tested, so development is often an on-going part of the job.

After the first aircraft is 'rolled out' (more significant to the press than to the engineers) the aircraft will be tested on the ground. Eventually it will make its first flight, and then it and further examples will embark on a flight-test programme. The flight-test phase is usually 15–18 months and can require 5 or 6 aircraft – or fewer if it is a 'derivative' rather than a 'new' design. Usually one complete aircraft structure is built and instrumented in a test rig on the ground, and although it will never fly itself, this test specimen will be the testing ground where aircraft longevity and structural safety issues are tested and have to be proved. Only after the landmark of certification, which follows successful ground testing and demonstration of performance, can deliveries commence to customers, and this will thus be

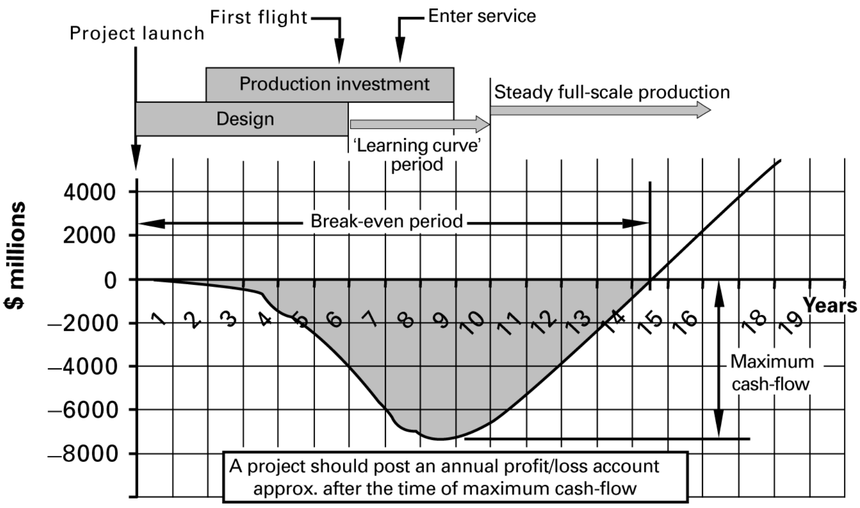
Table 5.1 Estimated current aircraft programme costs (Source: evaluations based on published data)

Project	Production rate (aircraft/year)	Maximum cash-flow ($ millions)	Break-even period (years)
EMB-170	48–72	1600–2000	16.5–17.5
Boeing 787-9	48–72	7500–10 000	16.5–17.5
Airbus A380	48	15 000	16.5–17.5

some 6 to 7 years after the project launch date. Production effort can already be intense, but the rate at which units appear is initially sedate, as the supplier chain gears up and the production workforce in the manufacturer and supplier workplaces progress along what is often called the 'learning curve'. That critical 48 aircraft per year production rate is illusive, with perhaps 100 aircraft delivered in the first 3 years and the full complement of 250 achieved over a 6- or 7-year period. This will be 14 or 15 years after the project was started, and the time involved is called the break-even period, for by the end date cumulative revenue (nominally now $62.5 billion for a programme such as the A380) will equal the costs to date. Clearly, that $10 billion investment requires a lot of further confidence, financially and technically, to get to the point where the programme is a business success for the manufacturer.

A cash-flow plot for a typical project will have a shape and a timescale similar to that shown in Fig. 5.1. On the diagram the maximum cash-flow value and the break-even period are annotated.

The data shown in Table 5.1 are illustrative. The range in cash-flow values



5.1 An aircraft programme cash-flow curve.

is based on assuming different levels of subcontractor liability, or cost-sharing. There are many hidden factors, perhaps subsidies that are unacknowledged, and pay rates from country to country can influence the costs greatly. In Brazil, where the EMB-170 has been developed, the labour costs are considerably less than in the USA or Europe, but the company relies on subcontractors that do face US and European costs, so while the illustrative estimates are good for comparison they may be wide of the real data.

All aircraft manufacturers face the dilemmas of trying to be 'lean' with their costs and having to bite off a higher level of technology as each new project comes up for funding. As Airbus proceeded with development of the A380 in Europe, Boeing, the leading US aircraft builder, decided to avoid a head-to-head with a new large airliner and took an alternative route, investing in a smaller but even higher-technology aircraft. Eschewing 'big is beautiful', Boeing set out to break the mould by using far greater proportions of carbon-fibre material (much lighter than traditional metals) and a not inconsiderable number of less obvious significant new technologies, in a bid to get a design that is a smaller (this is relative as it is still a 300-seat plus airliner) yet as economical to operate and (according to their estimations) more flexible alternative to the A380.

The actions of these two manufacturing teams have set the stage for one of the most significant tests of commonly held wisdom in the history of the modern airliner. Boeing will not get much change from a similar investment to Airbus, but their aircraft, compared to the A380, will be barely one-half the mass. They claim that because of the higher-technology content in its design, it should be as economical – in terms of seat-km per unit of fuel used and can show that it is able to deliver this performance from smaller airports, and to do that even if they are relatively close or almost on the opposite side of the world. Aptly, Boeing have chosen to name their airliner Dreamliner, and the prosaic 'family titled' Boeing 787 should become commonplace in the future.

It has been acknowledged that manufacturers are shy about revealing the true costs of their projects, but if the timescale suggested above is used as a basis and the educated guesstimates that contribute to the data presented at Table 5.1 are based on reasonable foundations, the sure indication is that each of these projects has locked a large part of each firm's resources to a project that will not bear fruit until around the early 2020s. It is also expected that these projects will still be in production as 2040 approaches, or passes by. There is no short-cut to quick-change in the aircraft building business.

The Brazilian Embraer EMB-170 has been used as an indicator, as it is a truly 'small' airliner with about 70 seats. Embraer have already developed and begun to supply examples of derivative airliners, ranging up to 125

Table 5.2 Aircraft prices (April 2006) (Source: Airclaims)

Airbus	$ millions	Boeing	$ millions
A318-100	21.9–28.4	737-300	6.00–15.6
A319-100	18.9–34.9	737-800	28.75–42.75
A320-200	11.95–42.15	747-400	37.3–107.55
A330-200	57.4–88.7	757-200	7–28.55
A340-300	46.8–100.16	767-300ER	19.4–67.75
A340-500	89.9–115.4	777-200ER	85–112
A340-600	92.9–126.4	777-300ER	67.5–136.3

seats. There is a belief that 'small is beautiful', largely stemming from analysis such as has been shown earlier in Chapter 1, where smaller aircraft offer more choice and easier access to less busy airports. There is also the possibility that smaller aircraft will bypass hubs and thus relieve congestion at hub airports. The Embraer (and Canadian Bombardier, which also has a 50–100-seat range of regional airliners) products are vying for this regime, against the 120–190-seat Boeing 737 and Airbus A320 derivative aircraft. The Boeing 787-9 and Airbus A380 will be the equivalent contenders at the top end of the market, with the A380 vying to assist in improving efficiency at hubs and the B787 trying to open the way for more point-to-point services. These are visions borne of late 20th century analyses that will be crucial to the shape of air transport operations in 2030 and beyond.

5.2.2 Aircraft price

The quoted prices for some leading aircraft types, at early 2006, are shown in Table 5.2. The range of data represents the price range for oldest and newest examples of each aircraft type, so where a type has been in production for many years the oldest aircraft, like used cars, are relatively much cheaper than new production examples.

There are tales of aircraft being bought well below the published price, which buoys optimism, but the circumstances have to be understood. In order to get a good discount, as with any purchase transaction, cash is more valuable than a presentation of credential, but just as important is timing. A good time to approach an aircraft builder is at a time of economic uncertainty. Just as the monthly production rate is beginning to wilt the builder could be in a position to offer a cut-price deal in order to hold a steady production rate, with a steady workforce, and thus to be in a position to respond more quickly to an upturn in demand when the sales situation improves. This is only possible if the market place looks certain to assure sales of this type in the long term. In terms of an example of business in

action, the manufacturer is actually forfeiting short-term profitability with a view to achieving financial viability in the long term.

Manufacturers do not give aircraft away, but in such circumstances they are likely to be receptive to assisting an established customer to make a good purchase and thus be more likely to return and do business with them again. Of course, the customer has to get their timings as good again to obtain as favourable a deal a second time.

5.3 Compatibility with the operational infrastructure

The cost of operating an airliner, as experienced by the operator, is also dependent on issues that concern operational compatibility and the regulations that arise from safety legislation. An essential requirement for an airliner is that when it enters service it interacts with everything around it in a compatible manner. The first way of providing such confidence is building the aircraft to established airworthiness rules, and it is therefore typical for all airliners to be designed to attain US and European 'certification'. The standards they use are the Federal Airworthiness Requirements (FAR) in the USA and the Joint Airworthiness Requirements (JAR) in Europe. They are similar in terms of structure, but subtly different at the content level. The implications of this paper 'qualification' in fact go very deep. The aircraft will have been designed according to well-defined design rules, and the design assumptions involved in its definition will have been monitored thoroughly so that the assured 'life' of the aircraft – hours or cycles – is a genuinely attainable target. A complete test specimen airframe will have been used to validate a lot of assumptions in this regard. Its systems and components, from engines to light-bulbs, will have been shown to be able to meet the needs demanded by risk assessments of failure cases. Stemming from these rather esoteric studies many operating principles will have evolved, which will be the basis of the safety management system (SMS) process content implied in the aircraft's type of 'certificate of airworthiness' (COA).

Hence, as it leaves the factory every aircraft has a set of documentation associated with it that will support both design-case evaluations and in-service operations. An aircraft flight manual (AFM), for example, will present performance data that have been validated in the design and flight test, and checklists will express crew responsibilities as procedures that arise from the risk assessments that have accompanied design and operating assumptions. Likewise, technical documentation will define maintenance programme needs that are justifiable against operating criteria. Each example of the aircraft type has an individual COA. It presents data confirming that the aircraft complies with the assumptions of the type of COA, quoting precise mass data, and so on. It is the responsibility of the

aircraft owner (and that might be a leasing company, not an actual airline) to ensure that throughout its operational life the attributes of the aircraft remain within the specification and that all who work on it adhere to the procedures appropriate to maintaining a valid 'certificate of continuing airworthiness' or 'certificate of compliance'. Such requirements mean that only appropriately qualified personal can take decisions in regard to the adherence of appropriate policies. There are no short-cuts, and aircraft can be 'grounded' for lack of due care and attention to any operational procedures. The many onerous requirements for an aircraft engineer's licence ensure that they can perform such duties effectively.

Achieving 'compliance' within the operating regime is a matter that clearly is linked closely to the regulatory and technical environments, as already described. Another matter is equivalent compliance within the operating environment, which means that the communication, navigation and surveillance (CNS) system elements that are used throughout the world are a part of the aircraft. There are many ways of doing this. At the minimum level – simply the interface – the aircraft will have a prescribed number of sensors and receiver/transmitting devices. How the information from these units is conveyed to the flight deck and presented to the crew can define several other levels of compatibility. On a small aircraft that is using the same airspace as a commercial airliner – an air-taxi type perhaps – the systems might present information in what can be described as a very 'raw' fashion. The airspeed indicator, altimeter and vertical-speed indicators might be simple pressure-sensitive devices that move a needle against a graduated background dial such that the desired quantity is shown in a suitable manner. On a large airliner, while the sensing devices might use the same principles as those on the air-taxi, the detected pressures might be converted to an electronic format in an air data computer (ADC), which will then transmit the data to the instruments or even to additional electronic units. One of these, on an EFIS-equipped airliner, will be the computer display unit (CDU), which will integrate the data into a TV screen style display and show the information on an electronic screen. Thus, the ubiquitous dials of old are not visible, at first sight, on a modern airliner's flight deck. (The components of these systems are described in Chapter 4.)

The technical regulation will have stepped in when design solutions were being developed within the aircraft development programme. In order to meet safety needs, there will be standby instruments, which might be old-fashioned looking devices (or on the very latest aircraft are very modern low-power liquid crystal display (LCD) units), so that a crew does not depend on a sole instrument. The majority of airliners have three sets of primary flight instruments and there are two crew members who can each compare the information on any two sets, at any time. Should a fault occur they can detect and reason the failure through a 'majority vote'. There is

also nothing to stop the design engineers inserting sensors into the computers and for their warning system to generate indications of non-catastrophic failures, possibly to a maintenance panel only.

A further addition in aircraft that are electronically equipped is to take the opportunity to integrate the paraphernalia of modern systems (such as AFCS, FMS, etc., as described in Chapter 4) that allow two pilots to monitor, decide and control all necessary aspects of on-board system operations. No matter how well these systems operate, in terms of taking away the workload associated with the primary flying tasks within a typical operation, the aircrew have to remain ‘situationally aware’. One of the greatest challenges within the operational regime of such extensively ‘automated’ aircraft is to implement operating regimes, ensuring that the desired safety level in operations remains high enough to keep accident rate statistics on the desired trend line, which is often a human–machine interface difficulty. The way it is addressed is through training regimes, which use techniques grouped under the title ‘crew–resource management’ (CRM). Within the CRM concepts that are used widely today, the crew learn to be responsive to one another and to be aware of and in touch with others. This can apply to controllers in the air traffic control (ATC) system or even the cabin crew looking after affairs within the airliner’s passenger cabin.

The operational processes described above and the consequent equipment requirements have an impact on operating costs. The procedures put in place are designed to monitor how well aircraft are operated, and thereby to allow warnings of potential compliance failures to be flagged, rather than left to occur. These are enshrined in safety management system (SMS) concepts, which every airline employee whose job entails an operational aspect will have encountered and had to reconcile with their desire to, at times, break the rules. There can be no breaking of the rules. If such events are recognised in monitoring procedures, severe consequences are as good as assured. This policy militates against minimising operating costs, but the aim is to balance the need to be adequately safe with the desire to be efficient. It is on this latter aspect that the next viewpoint on aircraft concentrates its gaze.

5.4 Direct and indirect operating costs

When the operation of an aircraft is portrayed in simple terms, it is usually expressed in terms of minimisation of costs. This is to do with efficiency, in that the more efficiently an aircraft is used, the cheaper it will be to operate. Operating costs are divided into two regimes, direct and indirect costs, namely:

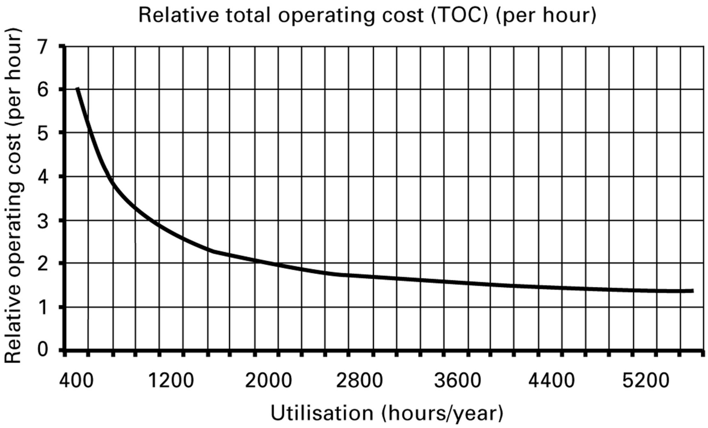
Table 5.3 Relative direct and indirect operating costs per hour related to utilization

Utilization (h/year)	X_i	X_d	Total
400	10.0	1.0	11
500	8.0	1.0	9
667	6.0	1.0	7
1000	4.0	1.0	5
2000	2.0	1.0	3
4000	1.0	1.0	2
8000	0.5	1.0	1.5

- Direct costs are those incurred at the time of flight. They will include crew salaries (factored to including training, etc.), fuel, on-condition maintenance, airport and air navigation service charges, and so on.
- Indirect costs are those incurred as a matter of ownership. The aircraft value, or the repayment lease if it is not fully owned, will be recovered as an annual repayment cost. Likewise there will be hull insurance, charges attributable to airline functions (administration, ticketing and reservation, building leases), and so on.

In terms of using an aircraft efficiently, this works between two extremes. Buy an aircraft and never fly it and it costs nothing in direct terms (but there will still be indirect costs) and its operating cost is theoretically an infinite cost per unit of production. Buy an aircraft and fly it every hour of every day of the year and one gets $(24 \times 365) = 8760$ hours per year from it. There will be a direct cost of X_d per hour and an indirect cost of X_i per hour, where direct costs are incurred at the time of use and it is usually acceptable to treat them as a constant 'per hour' cost. As indirect costs are associated with expenditure that must be recovered annually, as utilisation increases this will be a diminishing 'per hour' cost. If the direct cost is treated as a constant and the indirect cost is expressed as a proportional quantity based on hours flown, the total operating cost is the sum of these. The relative values are as shown in Table 5.3.

The utilisation value shown is based on the assumption (reasonable but not assured) that at 2000 h/year the indirect costs are twice those of the direct costs. If the aircraft was worked much harder – twice the utilisation – the simplest assessment is that the total operating cost will fall from 3 to 2 units per hour. If an operator uses the aircraft less frequently, and for as little as 400 h/year, the operating costs rise to 11 units per hour. Thus the costs are well on their way to being 'infinite' at zero hours of utilisation.



5.2 Relative total hourly operating costs.

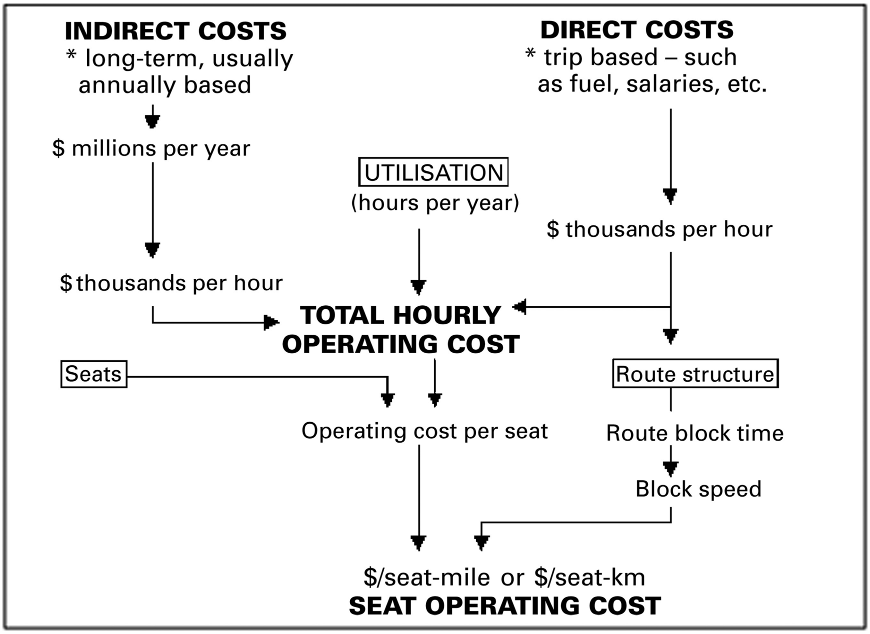
Note that once 8760 hours have been reached, the other extreme limit is reached, and at this point the relative operating cost value is 1.228.

Figure 5.2 shows how the total hourly operating cost can be expressed, in such a theoretical assessment, against utilisation. In reality, there are additional costs associated with very high utilisation values, and the total hourly operating cost does not necessarily follow such a gentle curve. It tends to rise at high levels of utilisation.

In terms of costs, an airline striving for efficiency will try to fly each aircraft for as many hours as possible, per year. They will know that to exceed the equivalent of perhaps 16 hours per day for a long-haul aircraft and only 10–12 hours per day for a short-haul aircraft will bring little operating cost benefit, given that there will be operational constraints that will affect the service quality, an issue that will be addressed in the next section of the current chapter. Examples of service quality attributes are delays that accumulate, leading to reduced despatch reliability, and the effects of curfews that occur at different relative times across time zones.

The way that the operating cost is expressed is usually derived from a process that takes account of the major influences and results in seat-km cost by applying a process that is illustrated diagrammatically in Fig. 5.3.

The components of such an assessment are influenced by utilisation, seats per aircraft and aircraft repayment agreements, and as these vary from airline to airline it means that any assessment of operating costs is always a 'ball-park' figure. The variations over a number of operators can be considerable. Some example operating costs, shown in Table 5.4, are based on data from late 2005 filed by US operators of Boeing 747-400 and 777-200; they show how different the data can be. The filed data have been used



5.3 Components of aircraft operating costs.

to evaluate the \$/seat and \$/seat-km operating costs for a nominal flight in each case, based on an 8-hour operation covering 6500 km.

It is always desirable to be able to express the operating cost of an airliner with reasonable confidence, such as being able to say that a new airliner is 15% better than an older type. The caveat is 'under the same operating circumstances'. Hence, it is important not to read too much into actual operating costs. At first sight, the B747-400 data suggest that Northwest operations are much more expensive than those at United. Closer inspection shows that indirect costs are almost double in Northwest, which perhaps indicates a younger fleet or even a smaller fleet (without the economies of scale). There is a similar difference in the B777-200 data, with Continental

Table 5.4 Typical aircraft operating costs (Source: US Form 41 reports, 2005)

	Direct (\$/h)	Indirect (\$/month)	Utilisation (h/day)	Assumed seats	Flight cost (\$)	\$/seat cost	\$/seat-km cost
747-400							
United	8697	298 916	12.1	400	76 863.7	190.41	0.029
Northwest	9155	588 846	12.6	400	85 507.6	213.77	0.033
777-200							
United	6568	95 618	12.0	330	54 672.8	165.67	0.026
Continental	6283	424 875	14.7	330	57 971.5	175.67	0.027

having the greater indirect operating cost. If this is because of a younger and more reliable fleet, this could account for why the airline also achieves 20% more utilisation per day. In this case the $/seat cost, which will be the yield target when airline operations are addressed in the next chapter, is thus almost the same on both airlines.

5.5 Balancing efficiency and effectiveness

Mention has been made of balancing efficiency with service quality attributes. Some of the service quality attributes arise from design and some from the way the aircraft is operated. These two roles will be discussed in conjunction, because it is the way that an airline uses the 'flexibility' that the designer offers that determines much about service qualities.

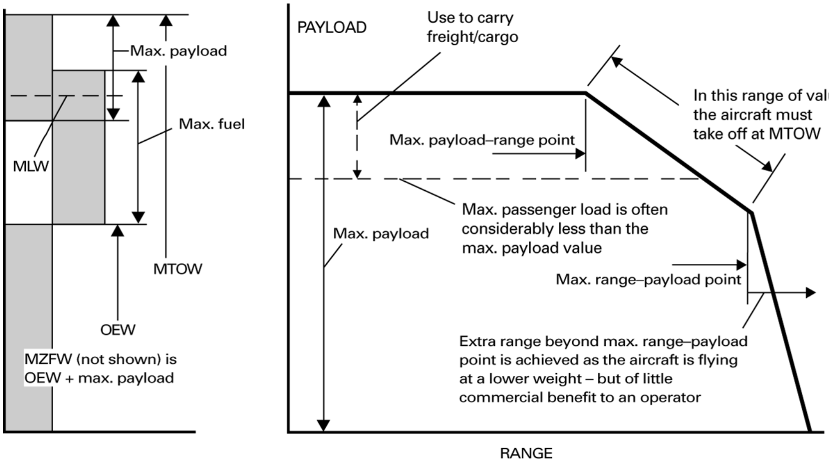
The designers are responsible for the actual efficiency. This is addressed, in a traditional design process, by consulting with users on their operational requirements. The actual requirement for an airliner can be a very detailed document. Some stated needs will be very detailed, but the principal requirements that will affect efficiency and effectiveness are far from numerous and for general analysis they can be expressed in terms of four main issues. These are:

- payload range
- operating speed (and altitude)
- maximum allowable field length performance
- target operating cost.

The design team has to hold a common 'mental model' of how the issues they address will affect the aircraft design. This process is engineering based and built upon an understanding of the four principal forces that affect an aircraft – lift, drag, thrust and mass – as well as being able to attribute the relationships that link them through these four properties of the design.

5.5.1 Payload–range

Payload is the fee-paying load that can be carried between the origin and destinations, excluding any fuel remaining on landing. Most aircraft are designed to trade payload and range, such that the maximum payload can be carried only a proportion of the maximum distance over which the aircraft will fly with a reduced payload, which might approximate to the maximum passenger load. Essentially, the design is limited by the design maximum take-off weight (MTOW), the maximum payload and the maximum fuel load. Because it is a statutory requirement, the MTOW can never be exceeded in operations. The other two mass values are interchangeable. A 'constant' in all of this is the operational empty weight



5.4 Aircraft masses and the associated payload–range diagram.

(OEW), being the weight of the aircraft prepared for service, but without passengers or fuel on board. The principle whereby fuel and payload can be interchanged, and how this translates into a payload–range diagram, is shown in Fig. 5.4.

Provisional data for the Boeing 777-200LR (where LR means long range) provide an example. The aircraft weights (taken from a generic Boeing specification – there are differences in service) are:

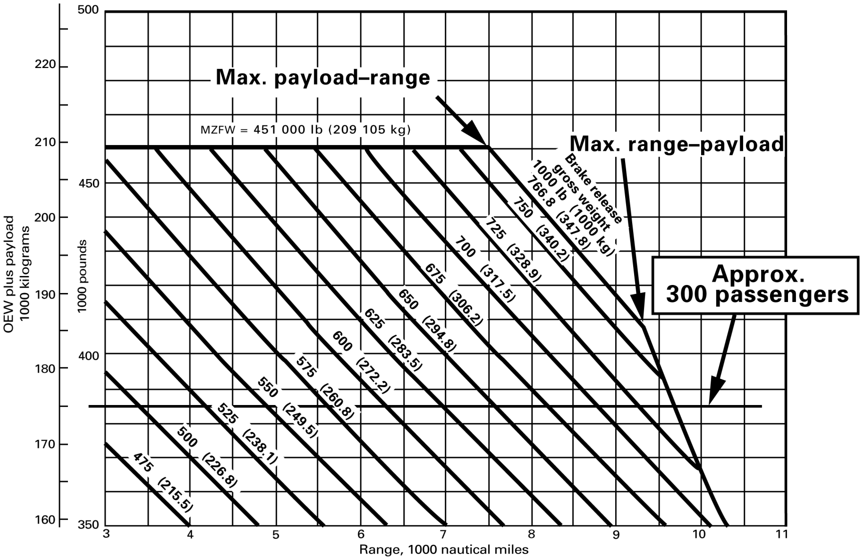
OEW	145 149 kg (320 000 lb)
MTOW	347 814 kg (766 800 lb)
Maximum payload	63 956 kg (141 000 lb)
Maximum fuel	145 541 kg (320 863 lb)

The aircraft is, nominally, a 300-seat design, and at 100 kg per passenger (including baggage) the typical full passenger payload will be 30 000 kg. The design has been configured to carry as much payload again, meaning that, potentially, it will accommodate considerable freight as well as passengers up to a certain range.

There are four notable points on the payload range diagram:

1 Zero range payload (this is the maximum payload).
2 Maximum payload–range (the greatest range that the maximum payload can be carried).
3 Maximum range–payload (the maximum range with a maximum fuel load and taking off at the maximum take-off weight.
4 Ferry range, the furthest that the aircraft can fly with no passengers.

The second and third points are the most significant on the payload–range



5.5 Payload–range diagram (Boeing 777-200LR) (Source: Boeing).

diagram, shown in Fig. 5.5, which is the actual payload–range chart for the Boeing 777-200LR. They can be seen to be where the limits of payload and range performance exist.

The sloped portion of the plot between the second and third points represents the aircraft's payload–range capability when it takes off at the MTOW. These are the critical design conditions that eventually show up as an efficiency and effectiveness trade-off. If circumstances do not permit an MTOW operation (due to departure airport runway length, local air temperature or elevation limitations, which are issues addressed in more detail later in Chapter 7) the aircraft will attain any payload–range combination up to a line that is displaced to the left on the plot. The sloping lines on the example plot are spaced 11 343 kg (25 000 lb) apart.

When striving to meet a particular payload–range objective, the designer has to be careful that the requirement does not prove to be a target that requires so much out of the design that the performance is compromised with regard to operating costs. The design in this case will carry 300 passengers about 9700 nautical miles; to put that in perspective, the aircraft (the 777 LR variant) will reach most major US cities from Singapore. It is a performance that has been attainable in only the most recent (post-1995) era of airliners.

5.5.2 Fuel efficiency

The conversion of this performance to a measure of fuel efficiency requires prior knowledge of what operating conditions have been assumed. In the majority of payload–range assessments the aircraft is assumed to cruise in still air and to carry a nominal reserve of fuel. Assuming the reserve is 8000 kg for the 777-200LR, there are two points where fuel usage can be evaluated. These are

Maximum payload–range (63 956 kg–7500 nautical miles (13 900 km)): fuel used 131 616 kg
Maximum range–payload (41 164 kg–9700 nautical miles (17 980 km)): fuel used 156 408 kg

These translate into per kg fuel burn figures of

Maximum payload–range	6754 kg-km per kg of fuel
Maximum range–payload	4732 kg-km per kg of fuel

Most airliners operate typically with 75% of attainable payload, so these figures diminish to around 5060–3550 kg-km per kg of fuel in normal service.

Compare this to a car that achieves 50 miles per gallon (in the UK this is 80 km from 2.55 kg of fuel) and can convey four 80 kg people (320 kg payload), which has an equivalent per kg fuel burn figure of

10093 kg-km per kg of fuel

This car, with reduced occupancy, attains

3 occupants	7570 kg-km per kg of fuel
2 occupants	5040 kg-km per kg of fuel
1 occupant	2520 kg-km per kg of fuel

These data show how relatively fuel-efficient a modern airliner can be. The actual fuel efficiency has improved steadily over gas-turbine airliner evolution. In terms of a benchmark, the equivalent full-payload use fuel data for the 707-320C of the mid-1960s was approximately one-half of the values quoted for the 777-200LR.

This fuel efficiency figure has been chosen as a benchmark because it is the kind of criterion on which civil aviation will have to hang its reputation in the increasingly environmentally enlightened age. It is difficult to evaluate precisely; the spread between the extremes shown is about 0.7:1 for the 777-200LR and it was in excess of 1:3 for the older 707-320C when equivalent data were evaluated. Even then, aircraft are not used to their full capability, which is also true of most surface transportation systems, so the full-

capacity data are perhaps the fairest comparison to cite, and in such light the airliner fares well.

Within the context of future operations, the current level of capability has to be improved. The way it will be done is two-fold: first, through detailed attention to technology and design that will enhance the vehicle performance and, second, through improvements in the way that aircraft are operated. The latter aspect will become a greater part of the considerations in associated chapters on airlines, airports and airspace.

5.5.3 Technical contribution to performance

Air-vehicle performance is technology-based, and as technology evolves so performance is improved. This links to a gradual change in airliner design criteria, and while aircraft configuration has been relatively static, the shape of airliners has changed subtly in recent decades. It could change remarkably over coming years as new performance demands are made by customers.

A new structural material having the most influence is carbon-fibre reinforced plastic (CFRP). The Airbus A380 uses some all-CFRP components and has a large proportion of the fuselage manufactured using a unique aluminium/reinforced-plastic sandwich (trade name 'Glare'), while the newer Boeing 787 Dreamliner and its even newer Airbus equivalent aircraft, the A350, will use carbon-fibre extensively. The Boeing design is in a more advanced state of development and is anticipated to have an almost all-CFRP fuselage shell and CFRP wings. Airbus A350 plans are based on a similar technological basis.

CFRP offers durability and is relatively light. The designers have to exploit the potential weight saving with care. For the 787 Dreamliner Boeing has allied airline requests for fuel efficiency improvements with a desire stemming from other areas of concern in the airports and airspace environments to offer more flexibility in operations. This is an early indication of the needs of the air transport system as a whole taking a part in the debates that range outside their direct area of interest. Boeing believe that the 787 will offer better fuel efficiency over a wide combination of payload and range values, and they also believe that being a smaller aircraft than most current long-haul types it will offer the opportunity for more point-to-point operations. The analysis of route networks in Chapter 1 has shown that airline hubbing is often the reason that some airports become congested, while others see their direct-route possibilities diminished. The 787 is being marketed as an aircraft capable of making hubs a thing of the past and opening more direct routes. The converse solution is to offer more capacity per movement at hubs, which is where the 600–800-seat A380 will be exploited. The reality will be, surely, that both types will make their mark.

Where the 787 is particularly significant is that the design is using the new technology adroitly. The aircraft wing is very flexible and in its detail it is indicative of a push to achieve a higher aerodynamic efficiency (a higher lift-to-drag ratio). This will reduce fuel-burn, and will be improved by using engines that are achieving better fuel-burn performance than earlier generation engines. The combination of aerodynamic and propulsion system improvements should set a new benchmark, and on preliminary performance data released by Boeing (at September 2005), the fuel efficiency at the maximum payload–range point was shown to be 33% improved on the 777-200LR. There is probably some optimism in this figure.

This has been achieved in one generation (there was an interval of about 15 years between the launch of 777 and 787 as projects), and exemplifies not just commitment by the manufacturers and their major suppliers to achieving significant environmental improvement but also in exploiting technology. In so doing, they do not minimise the cash-flow on their programmes and the risks they take are considerable. Most major companies involved in airliner design and suppliers such as aeroengine companies all delicately tread the lines that delineate technical and financial risk.

Aircraft efficiency is measurable in many ways. Some tabulated data regarding leading features of some significant aircraft types that have been introduced over the last 40 years are presented in Table 5.5 to exemplify briefly how some intuitive, and sometimes counter-intuitive, developments have taken place. Behind each of the strides that has been made in the evolutionary tale there is always also a tale of risk management on a grand scale.

Fuel fraction is a measure of the maximum fuel load as a proportion of the maximum take-off weight and is often quoted as a measure of technical efficiency. In the course of their life, short–medium-haul aircraft tend to complete more flights than long-haul aircraft and are more robust in terms of their construction. The consequence is that the fuel fraction is always lower than that of long-haul aircraft. (The differentiation is not so clear-cut, and the Boeing 757-200 and 767-400 are aircraft capable of trans- Atlantic operations and their fuel fraction is noticeably higher than other aircraft in their category.)

Listing the selected types in date order emphasises the fact that fuel fraction is not tending to rise, although it was expected that it would as lighter-weight structural materials became available. The observation is that as more fuel-efficient engines have been developed, the necessary range performance has been attained with smaller and less heavy aircraft.

The tendency for the key aerodynamic efficiency indicator, the wing aspect ratio, to rise with time is evident, albeit the rate of increase is slow. There are always exceptions to the rule. The A380 has a relatively low aspect ratio, which is attributable to the need to provide a given wing area but to fit

Table 5.5 Fuel fraction and wing aspect ratio (span^2/area) for different aircraft types (bold typeface shows short–medium-haul aircraft) (Sources: various)

Date of first flight	Type	MTOW (kg)	Maximum fuel (kg)	Wing area (m^2)	Wing span (m)	Fuel fraction	Wing aspect ratio
Aug 59	Boeing 707-320	151 500	72 503	283.0	44.42	0.479	6.97
Nov 59	Boeing 720	106 500	48 903	234.2	39.88	0.460	6.79
Apr 67	**Boeing 737-200**	**52 610**	**14 520**	**91.1**	**28.35**	**0.276**	**8.82**
Oct 72	**Airbus A300-B4**	**165 000**	**46 654**	**260.0**	**44.84**	**0.283**	**7.73**
Sep 81	**Boeing 767-200**	**142 882**	**50 753**	**283.3**	**47.57**	**0.355**	**7.99**
Feb 82	**Boeing 757-200**	**115 650**	**34 260**	**185.3**	**38.05**	**0.396**	**7.96**
Apr 82	Airbus A310-300	123 000	59 637	219.9	45.89	0.485	9.62
Feb 87	**Airbus A320-200**	**77 000**	**19 959**	**122.6**	**34.09**	**0.259**	**9.48**
Apr 88	Boeing 747-400	396 894	174 093	541.2	64.44	0.439	7.67
Jun 94	Boeing 777-200	286 900	137 460	427.8	60.93	0.479	6.68
Aug 97	Airbus A330-200	233 000	112 067	363.1	60.30	0.481	10.01
Oct 99	**Boeing 767-400**	**209 111**	**73 363**	**290.7**	**51.92**	**0.351**	**9.63**
Aug 00	**Boeing 737-900**	**79 016**	**20 894**	**122.6**	**34.09**	**0.264**	**9.48**
Mar 01	Airbus A340-600	368 000	156 487	437.0	63.70	0.425	9.26
Apr 05	Airbus A380	560 000	253 175	845.0	79.80	0.452	7.53
2008/9	Boeing 787-9	230 652	100 127	c.360.0	60.1	0.434	10.03

into an apron stand ‘footprint’ that is 80 metres square. Hence aerodynamic efficiency has been compromised in order to make the aircraft compatible with modern airports.

5.5.4 Operating speed and altitude

The cruising speed of all jet airliners is about Mach 0.7 to 0.9 (410 to 527 knots TAS), with most concentrated in the lower half of this band. Some designers have attempted to offer speeds between 0.82 and 0.88, but the aerodynamic performance is affected by increasing ‘wave drag’, which is attributable to the development of the supersonic shock wave that occurs at the speed of sound. To penetrate this region the wing has either to have increased sweepback or reduced thickness, and the trade-off with other performance attributes has never been acceptable. Technology developments could change that, but for the time being the short-haul airliners tend to cruise between 410 and 450 knots and have modestly swept and relatively thick wings that offer best field performance and good climb efficiency, while longer-range airliners have more swept-back wings and pay a price in terms of runway length requirement on take-off and landing, and cruise between 450 and 500 knots, with 480 knots being a very typical long-range economical cruise speed.

These speed targets are achieved at between 30 000 and 45 000 ft. The

shorter-haul aircraft use the lower altitudes, rarely climbing above 36 000 ft, whereas long-haul aircraft will use the higher altitudes. The latter is subject to aircraft mass, for on a very long-range flight the aircraft will be so much heavier at the commencement of cruise that it might not be able to climb above about 32 000 ft. For best performance aircraft should conduct a cruise–climb, with the aircraft steadily increasing its cruise altitude while maintaining a constant speed as fuel is burned and mass reduces. This does not tend to happen, as airspace service providers require that aircraft stay at a designated cruise altitude. They do allow a long-haul flight to climb in steps throughout the cruise phase. This is not as efficient as cruise–climb and is a topic on which there will be more to say in the later chapters.

5.5.5 Aircraft field length performance

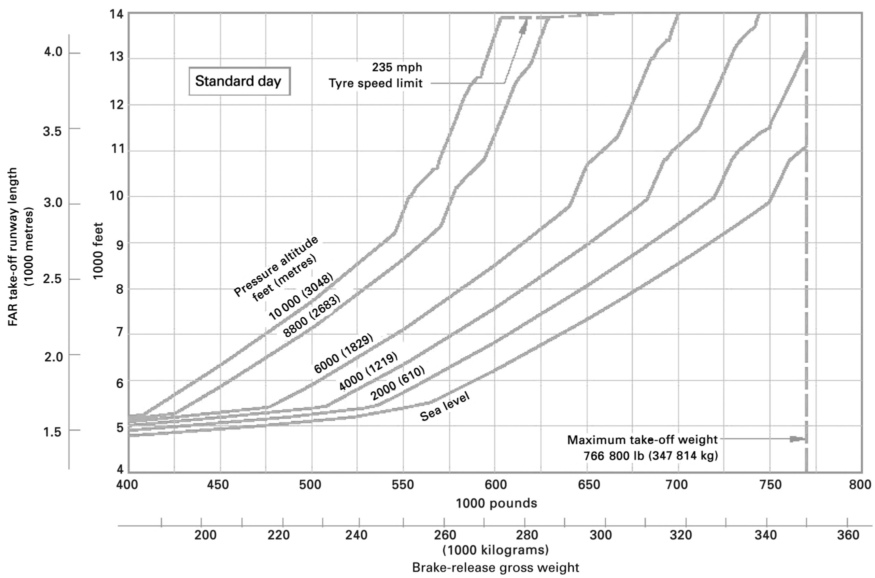
Consideration of cruise performance has intimated a trade-off with field performance, but there is much more to this. In essence, the larger the wing, the slower the take-off and landing speeds, and thus the less length of runway is needed to accelerate on take-off and to decelerate on landing. The actual area that will be needed, compared to the area needed for best fuel efficiency in cruise, is huge, and the palliative that overcomes this dilemma is the aerodynamic flap on the wing trailing-edge and slats on the leading-edge. As flaps and slats are extended, they increase the degree of curvature in the cross-section, the so-called wing camber, and allow a given lift force to be generated at a lower speed. The flaps create drag, so they are used sparingly on take-off (when a small flap extension will bring considerable lift benefit without as much drag increase as with larger flap extensions), but on landing the extra drag is tolerable because the aircraft is lighter. The extra drag both reduces speed sensitivity and helps to improve the descent angle, making it easier to reach a designated aiming point on the runway. Flaps are a nuisance as they are complex devices that add mass and increase the maintenance burden. Many types of flap configuration have been used as designers have sought to trade-off mass and cost implications in an equitable fashion.

The considerations introduced so far have shown that take-off is critical in terms of being able to take-off within an acceptable runway length. Safety regulation plays a large part in determining what will be acceptable overall, and the most significant failure case to consider – and the one that all pilots train to face, but hope that they will never do so – is the loss of an engine at take-off.

Aircrew do not work in distances. They use what is readable on their instruments and what is critical to aspects of performance, chief among which is speed. A safety requirement is that in operation the aircraft should be able to accelerate to a certain speed, with all engines running, and that

should an engine fail at this speed the crew should have enough runway ahead of them to execute either a take-off (with an engine failed) or to stop (assuming they will have brakes only). This is the take-off safety speed (called 'vee-one', presented as V_1). The handling pilot will be 'heads-up' and watching the runway and the supporting pilot will be 'heads-down' monitoring speed. The supporting pilot calls V_1 when the computed speed has been reached, and it is at that point that they know the take-off can no longer be abandoned without running out of runway length. The three major conditions that determine the safety speed are aircraft mass (or weight), airfield elevation (or altitude) and air temperature, and these are used to form the acronym WAT. Figure 5.6 shows the take-off field length performance of the Boeing 777-200LR for ISA standard day temperature. In order to assess other temperatures, further charts would need to be consulted and a take-off field length determined by interpolation.

A take-off field performance chart shows that the longer the runway, the greater the take-off weight that can be achieved, and hence the greater the payload–range capability of the type can be exploited. The higher the airfield elevation and the higher the air temperature, the more runway length is needed to achieve a given take-off mass. These issues will be re-visited in Chapter 7, where airports are considered.



5.6 Take-off performance chart (Boeing 777-200LR) (Source: Boeing)

5.5.6 Typical operating costs

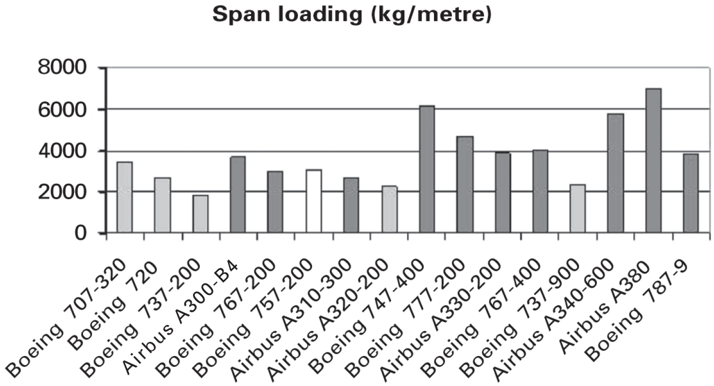
The structure of operating costs and their dependence upon many operational variables has already been explored (Section 5.4). The actual cost on a particular flight will also be affected by such issues as the payload–range and runway length available. If the payload–range is limited, by either airport elevation, runway length or air temperature, the operating cost will be affected in some way. It is always important to gather as much information as possible about the proposed operation, right down to knowing whether freight will be a significant part of payload and what en route weather conditions (especially wind direction and speed) will be frequently encountered. The dependence on the variables outlined will remain the same, but there will be limitations imposed by operations that will sometimes militate significantly against achieving optimum performance. These are considered within the context of airline operations in the next chapter.

5.6 Effectiveness

In addition to being efficient, aircraft have a considerable impact on many issues that can be referred to under the 'service quality' banner. If little regard is taken for the norm, the differences can have an effect on operations that range from irritating to catastrophic. Some indication of the way these are tailored alongside the efficiency and cost issues already explored is relevant here, with the objective of setting out, in addition, the way that an operator's wish-list for non-technical operational parameters can be related to the design. For example, the way that airport stand dimension requirements have been allowed to play such a great influence with regard to the A380 design (it has a 79.7 m span, against a requirement that it should not exceed 80 m) is an indication that not all technical matters are assessed and decisions made solely on technical efficiency criteria.

5.6.1 Wake-vortices

A significant operational consideration is that wings create a swirl around each wing tip, called a tip-vortex. This swirls inwards, causing a 'downwash' behind the aircraft. Sometimes the swirling flow is turbulent and so energy-laden that any aircraft entering into this region of flow will face the possibility of being upset. This is called wake turbulence, and thus if the vortex strength is large enough to cause the 'upset' of a following aircraft, the separation between it and any following aircraft as they approach a runway has to be increased. This can reduce the attainable runway capacity,



5.7 Span-loading: comparing categories of 'heavy' jets.

thus affecting the total amount of traffic that can be handled in busy periods at an airport.

A rough indication of the vortex strength is provided by the span-loading (mass per unit span). Based on MTOW, the span loading has been plotted as a bar chart in Fig. 5.7 and the most vortex-critical types are the darker bars. Interestingly, the Boeing 757-200 has been classified as an aircraft that needs extra approach separation behind it, although it is not, on this assessment, significantly worse than smaller aircraft. A perplexing problem for the A380 design team has been ensuring that the vortex behind this very large aircraft does not upset following aircraft. The impact of this issue on airport runway capacity is considerable, and it has been important that Airbus show that their new aircraft will not require any substantial change in spacing between successive arrivals.

5.6.2 Cabin dimensions

An airliner's fuselage is usually a tubular, streamlined, component that accommodates the crew and payload. It might also enclose fuel tanks and even have space devoted to stowage of the landing gear. There will be the flight deck, where the aircrew sit, the passenger cabin, with seats, galleys and toilets, baggage and freight holds, and small regions that are packed with electronic systems used to communicate or navigate the aircraft and perhaps to assist in its detection in surveillance systems.

The most important design consideration is the selection of a cross-section. As aircraft cruise high in the stratosphere, the air pressure within the passenger cabin has to be much higher than it is in the atmosphere. To accommodate the pressure differential at typical cruise altitudes (it is about half the sea-level atmospheric pressure) makes designers prefer a circular, or near-circular, cross-section. An oval cross-section is desirable for multi-deck

aircraft, so that the 'walls' are reasonably close to being vertical, but the Boeing 747 experience has been that the structural loads can cause the oval-shaped frames to crack sooner than circular frames, thus diminishing airframe life. Nevertheless, Airbus has adopted a very noticeably oval section for the A380, which has three decks – two for passengers and one for the baggage and many of the aircraft's systems. Newer materials (in the case of the A380, an aluminium/carbon-fibre sandwich) offer the prospect of balancing the requirements of obtaining a lightweight design and a structure that has good fatigue-resistance. Boeing is using carbon-fibre fuselage sections for the first time on an airliner, on the 787 Dreamliner, and this promises the prospect of a less maintenance-intensive design solution, thus offering long-term operating cost savings.

In all airliners the passenger accommodation is invariably in rows of seats set a fixed distance apart (the seat pitch) and with seats in double or triple sets next to the windows. A small aircraft might have only three or four seats per row, and up to six seats if the cabin has just one aisle. These are narrow-body airliners. Larger-diameter cabins have two aisles and a central set of seats. This is usually only justifiable (in that the wider a cabin, the more frontal area it has and the more drag it will generate) when it is able to accommodate eight or more seats in a row, with ten seats the maximum number used, in an approximately 6 m (about 20 ft) diameter cabin.

The different cabin configurations that airlines use are discussed in the next chapter, when the seat pitch and other comfort factor issues are examined at the same time as user operational and business strategies. It is usual to have facilities – galleys for food storage and distribution (very rarely for preparation) and toilets – fore and aft, with some mid-fuselage facilities on larger aircraft. All airliners have the passenger access doors on the left and galley or servicing doors on the right. The underfloor baggage access doors are also on the right, these being conventions that make aircraft compatible worldwide with air-bridge or air-jetty access facilities at airports.

The ability to tailor seat configurations to meet different ratios of galley area per passenger, number of passengers per toilet, in-cabin baggage space per passenger, aisle width or total space per seat is not trivial for an airline that is trying to win the accolade of 'best airline' against their competitors. The airline that asks for a little more width is unlikely to be listened to for to redesign a fuselage is a multi-million (if not billion) dollar job and will take years. Sensible use of the available cross section is crucial to success, and this will be referred to again in Chapter 6.

5.6.3 The flight deck

The evolution of this part of airliners makes an interesting case study, not least because as systems have been made simpler to use, the crew size has

diminished, and now almost all aircraft have a two-place flight deck for the captain and first officer. In the 1950s the long-range airliner had two pilots, a flight engineer, a radio operator and a navigator. These three additional crew members still have a place on a few older aircraft, but everything on the drawing board since the mid-1970s has had a two-place crew compartment.

The systems that have wrought so much change need to be examined, to see where technology has been applied, almost invisibly, but on a massive scale, as the changes that have taken on historical connotations are liable to be overshadowed by as much change again in the future.

Of the three crew members that have been automated out of existence, the flight engineer has been the most recent to go. In their day these crewmen nursed the aircraft's engines and monitored a myriad of systems, of which fuel, electrical and hydraulic systems were the most operationally important. They would also control air conditioning, perhaps responding to passenger requests fed to them via the cabin crew. Modern engines have built-in monitoring and electronic control systems, and can be relied upon to perform flights without human intervention, except when the crew respond to a hazardous mechanical failure. Knowing what represents the most significant failure conditions, engines are festooned with sensors that not only record 'health' but even store it and transmit it electronically to the aircraft's operational base. If an engine begins to misbehave, benignly, the crew are among the last people to be informed, and often become aware of concerns only when engine technicians await their arrival at the next airport. The systems that do this have already been described in Chapter 4 on the operational environment.

5.7 The manufacturer's overall remit

In terms of what they do, the foregoing sections have set out how the aircraft builder has two important 'in-house' objectives: first, to run a financially viable business and, second, to ensure that their product is compliant with the safety and operating rules set out by the operator's own regulatory authorities and the providers of airspace services in the regions of sky within which the aircraft will be used.

Additionally there are technical objectives that must be addressed and result in an aircraft whose capabilities will meet user's expectations. In terms of how the user will see the product, the most important indicators (of a myriad of indicators of efficiency) are the payload–range, operating speed and altitude, runway field length performance and operating cost data. Finally, the degree to which the aircraft is compatible with operator needs, from crewing levels to door locations, and the scope for innovation service initiatives, in what can otherwise be regarded as just a bland passenger-

carrying tunnel, has been expressed as effectiveness objectives. Balancing these issues and respecting the changes and increased expectations of customers are what make the task of designing and manufacturing aircraft an exacting, albeit not always 100% scientific, endeavour.

There is still room for some 'individuality' to creep into airliner design, although if the constraints faced are not fully respected by designers, the most innovative solutions can be conspicuous failures. This chapter has briefly expressed how aircraft builders try to maintain a balance between financial, statutory, efficiency and effectiveness requirements that are as challenging as ever before. In this regard they do not stand alone, as a similar mix of needs faces the stakeholders in other contributors to the industry – airlines, airports and airspace service providers, for example. When all their needs have been qualified there is scope to consider whether the individual parties should keep their own objectives in mind, above all else, or whether there are more all-embracing objectives that can be recognised as emerging and that everyone needs to address.

6
Airlines

Abstract: This chapter explains how airlines serve demand and provide capacity in a manner that suits the capabilities of their fleet of aircraft. Airlines aim to operate viably and to set standards that will be a stiff target for any competitor. In responding to economic forces, airlines frequently change their operational principles, but they keep close to a 'brand' image. Airlines are where people seek the product they want and with whom they enter into a service agreement. This chapter unravels the issues they vie to balance and presents them as attributes that can be grouped in a way that is compatible with other system elements.

Key words: airline objectives, route and fleet selection, aircraft operating costs, yield management, passenger service quality, airline scheduling and timetables.

6.1 Introduction

Airlines can be like cities, in that, in terms of what they do they are all alike, but compare any two and the variety of different experiences can be remarkable. There is close to a guarantee that the attributes of such experiences will change over time, so revisiting will bring recognition of changes. Sometimes this is welcome and sometimes less so. Within the community of airlines, some have succeeded in keeping their 'brand' over many decades, but usually the only real 'constant' has been their colour scheme. Beneath the skin, most airlines change the principles on which they operate frequently. Some move rapidly, often changing direction in a strategic sense as they respond to economic forces, and some oscillate between service concepts as they vie to try what is new, but seem reluctant to dismiss what has served them well in the past. To the public, airlines are the industry's façade. They are where people seek the product they want and with whom they eventually enter into service agreement. Somehow a way

has to be found of describing what it is that drives these businesses, which all do the same thing but often so differently.

6.2 Setting up an airline

Setting up an airline invites some reflection on what common ground can be identified. First, an airline must have an owner, or owners, whose interest will be largely financial. If the ownership is private, long-term profitability can be expected to dominate commercial strategies, but if the airline is in public ownership it might have a remit to meet socioeconomic objectives and qualify for subsidies. For example, being a ‘flag carrier’ for a small or less than prosperous nation can be an unprofitable business, but if the reigning government believes that the losses it underwrites on the airline balance sheet are offset by positive contributions within its wider remit, which can include deterring foreign airlines from diluting the national economy by siphoning revenue into their own economies, they will often support such a venture.

Second, an airline must decide where it will be based. In terms of regulatory oversight it is essential that an aircraft operator applies for a licence to operate in and around the area of jurisdiction of an aviation authority. The airline will thus have aircraft registered in that nation or within a nation that is recognised as offering the necessary regulatory approvals. This process cements an airline into the regulatory environment. In setting up their operation they are now obliged to keep their core functions transparent to the regulator. The initial requirements are simple – declare ownership, base and mission statement. Then the regulator wants to know who will hold key posts, and they will want declarations of flight purposes, typical destinations, aircraft types and technical documentation, such as aircraft flight manuals and individual aircraft maintenance histories and schedules. The process of licensing an airline takes considerable regulatory effort and is a substantial up-front cost. The aim is not to impose bureaucratic largesse, but to ensure that, from day one, safety is given as much forethought as financial performance. In most counties a brand-new airline will take six months or so to set up from scratch, although devolving an airline from an existing operation, either through expansion or post-merger or bankruptcy, can reduce this estimate to a few very busy weeks.

The financial and operational objectives of an airline will arise from knowledge of issues that have been addressed under the term ‘natural environment’. There will always be demand for air services, wherever they are proposed, but the circumstances of each possible service have to be understood. The proposing airline must ensure that the demand is substantial enough to justify an operation and that facilities compatible

with demand are available, or put in place. In the latter area an airline begins to tread in airport and airspace issues, and while the constraints in these areas are of concern to an airline, traditionally the solutions are regarded as beyond their concern.

What an airline looks for in an airliner has already been debated in Chapter 5, but the route to the issues that have been discussed can look very different when they are viewed from the airline's perspective. Intrinsically, airlines, from the knowledge they have of the services they want to offer, will look for an aircraft that has the kind of performance they want. This means that they will associate performance with payload and range capability, speed and thus time between origins and destinations, and seat-km operating costs. The latter is the source of most debate, in that, as has been shown, the airline can influence the actual cost by choosing what utilisation they will aim to achieve, how many seats they will install, what customer service features they will underwrite (which might extend to taking control of the passenger's comfort in periods prior to, and beyond, the actual time that they fly on the aircraft) and what direct costs will arise from decisions that they take. This can be influenced by choices of salary scales, aircraft lease or purchase agreements, technical and customer service subcontracting, advertising and marketing, and so on. Airlines have considerable freedom in these areas, and it is where the ethos that will make them a different, or not, flying experience will reside.

It is unkind to paint a picture that presents the airlines merely as aircraft shoppers, but beyond influencing what is put on offer they do tend to consume 'technology', buying and using what they can get to suit their own purposes. They monitor their own performance, as a service-provider, dissect the consequences of actions and initiatives – both their own and those of others – and keep an eye on what technology has to offer. They will encourage their suppliers – of aircraft certainly, but all the other supporting players in their sales and service supply chains – to match their shopping ideas with solutions that are more innovative than they were hitherto. Airlines therefore can stimulate the adoption of new technologies and they expect engineers to sell them their ideas based on financial and service quality benefits. Airlines are not easily swayed by innovation alone. They are increasingly aware of the fact that new perspectives are necessary and they willingly embrace 'change', but are also aware of the fear that comes from entering the unknown.

Planning is often hemmed in by constraints that arise in 'operations', which can be the airline way of segregating limitations that are imposed by airports and airspace providers. Some airlines groan that these are sources that are external to their remits, and while they will campaign for change they contribute nothing. More mature managers and analysts gauge ways to react to these problems. Their attitude, typically, is contributional rather

than confrontational, and it is that kind of spirit that needs to be rewarded in the fullness of time. The progress that they contribute is possible only when common indicators are identified and long-term action plans that will serve the needs of the user and not place impossible demands on the supplier have been expressed, addressed and rectified. This is an area of endeavour that requires an understanding of the processes and capabilities that affect all the contributors to the overall air transport system.

For now, keeping within the airline domain, their service requirements have increased in complexity gradually over time. In simpler days, an airline manager was regarded as the custodian of a noble and prestigious business. An airline set levels of expectation for their customers that heralded adventure and had romantic inclinations, and they were high-profile businesses that demanded headlines when they set out to offer new travel experiences. Many airlines still want to promote themselves as inhabiting this lofty regime, but as the breadth of usage has increased the range of business strategies has opened greatly. There are scheduled carriers that cater for business and low-cost demand or who specialise in leisure travel, and there are even carriers that try to appeal across all these categories. Nowadays airlines fly billions of passengers annually, and while they can be broadly pigeon-holed as 'flag', 'private' or 'public, 'scheduled' or 'charter', 'low-cost', and so on, they are far from simple businesses.

The fact that the 'model' for an airline has broadened so much, and that the change process has occurred largely on the tide of technological influences that have reformed media and public habits throughout developed and developing societies across the world, testifies to the fact that they are also among the most modern of businesses. The metamorphosis that has characterised recent decades seems sure to continue. Some cherished working practices will persist, but newer working practices will arise as time goes by. Integrating these into a business scene that is forever more complex, and thus tends to be less amenable to change, is a challenge of utmost importance to the businesses involved.

6.3 Modern airline objectives

Aircraft have always won over other modes of transport by offering a 'faster' (and more convenient?) way to travel to/from destinations. Because of their service speed and convenience, they overtook railroads as the preferred way of conducting 'long-distance' travel throughout Europe and North America. Payload expansion has also been a continual objective, with the belief, almost enshrined and partially demonstrated to be true in consideration of aircraft attributes, that the bigger the aircraft, the lower the average seat-km cost. Airliners designed to serve specific market segments have got bigger with each generation, and as airlines have sought to serve

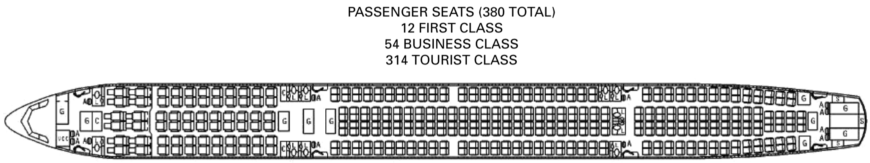
more routes, the financial properties of the operating businesses have grown at a faster rate than the size of the aircraft they use. Meanwhile, the price of air tickets has reduced, in relative terms, from enormous to almost trivial (but marketing techniques can disguise like-for-like).

In an economic business, efficiency is not as easy to define as it is in engineering, where attributes often sit on a 0 to 100% scale. Some of the physical constraints on operations can be viewed and expressed through equivalent windows, a prime example being aircraft utilisation. Flying an aircraft only 8 hours per day (about 2500 h/year) has been shown to increase operating costs considerably over flying an aircraft at double this rate. The operating cost is affected by so many variables that the improvement is not as simple as saying that doubling of one leads to halving of the other. The way that service support is organised and costs are distributed can have a bearing that will affect operating cost, no matter what the annual utilisation figure might be. Some efficiency indicators have to be found, but there are few parameters that will yield a recognisable datum in this complex field.

Service effectiveness is an even more difficult issue to enumerate. Consider the way that the number of seats can be increased or decreased in an airliner's cabin. The impact on operating cost has been seen to be considerable already, but the relationship here is complex, with the efficiency and effectiveness impacts following different paths, and offering 'windows' of opportunity that an airline can choose to exploit fully or partially, in conjunction with pricing and marketing strategies.

The seating plan shown in Fig. 6.1 exemplifies a 380-seat three-class (12 first, 54 business and 314 tourist class) cabin plan for an Airbus A340-600. It is a configuration that would be suited to long-haul operations. If the seat data for these configurations are used and a nominal \$54 000 operating cost figure for a 12-hour operation is assumed, the revenue requirement of each seat is as shown in Table 6.1. (The operating cost has been proportioned across cabins on the basis of proportion of cabin length occupied: 9.6% first, 20.2% business and 70.2% tourist.)

The 100% seats filled data are where a strategist will begin to assess actual operating costs. This means that an airline using the 380-seat cabin will expect the total passenger load to contribute \$142 per seat on the flight. They might pay more than this or less than this, and some seats might not be



6.1 Airliner seating configuration (Source: Airbus).

Table 6.1 Seat revenue requirement to cover the operating cost: hypothetical operation

	Load factor				
	100%	90%	85%	65%	45%
380 seat	$142	$158	$167	$219	$316
380 seat:					
314 economy	$121	$134	$142	$186	$269
54 business	$202	$224	$238	$311	$449
12 first	$432	$480	$508	$665	$960

filled; the 90% seats filled value quotes ($158) would be a nominal ticket price for a low-cost operation. The three-class case shows a more detailed assessment with a nominal ticket price for each category derived on an expected proportion of seats filled. The process has shown a way of justifying the kind of fares that are encountered on a daily basis: for example low-cost operator $158 (90% load factor) and scheduled operator $960 for first class (45% load factor), $311 for business class (65% load factor) and $142 for economy (85% load factor).

Among other parameters that are also used routinely to express efficiency are measurements such as passengers (or passenger-km) per employee, but care needs to be taken. For example, employee data can be skewed by the use of subcontractors. Another widely used indicator is the passenger average load factor (percentage of seats filled per flight), which has already been introduced.

When airlines take account of the passenger's perception of value for money, they are viewing service quality indicators. For example, delays are related to despatch reliability and are a prominent technical benchmark, but there can be many others. Among those exemplified above are the size of seats and the relative level of fares, but often viewed internally and rarely discussed in the open is the frequency with which people are refused a seat or are told that a flight is 'overbooked'.

Over a number of decades the changes that have affected strategy have emerged from technology – in aircraft, in support services (especially concerning computerised ticketing and reservation systems) and within the community (through improved media access and the ubiquitous 'internet'). These developments, and some that have not yet been envisaged perhaps, determine how managers set out plans that will meet mission objectives. It is that process that will be used to structure the next few sections. They will look at route selection and development, at aircraft selection (fleet planning) and fares policies alongside scheduling and other operational issues. Finally, efficiency and effectiveness, according to some of the criteria already

recognised, and the way they can be expressed and measured, plus the inevitable question of financial success, are considered.

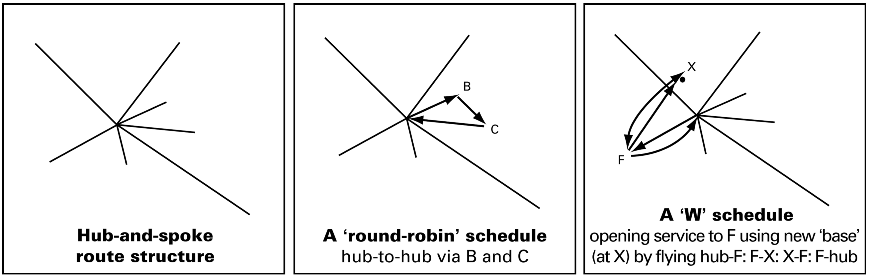
6.4 Route selection and development

In 'deregulated' countries the right to fly a route is entirely at the airline's discretion, subject to there being capacity to handle the required movements at the departure and destination airports. Meanwhile, operations between nations are still constrained by bilateral agreements, whereby many airline service parameters, such as destinations, frequency of service (flights/day or week), capacity (seats/week or even seats/flight), facilities offered (drinks and food, entertainment, etc.) or price, can be state-enforced through a common accord. All such restrictions tend to be politically motivated, and the belief is that they are constraints that will be removed in the fullness of time. This has always been optimistic, but the walls have begun to crumble since about 1980.

Airline traffic forecasters take such issues into account and devise route structures that they will negotiate and thus provide. The process of traffic demand modelling has already been explained (Chapter 2). Summarily, it might be an extrapolation of historical data or a model-based estimation process, validated against historical or comparable route data, and it might include assumptions on market-development trends. However it is generated, the traffic forecast is the bedrock of an airline's plans. If a company is gambling all, there is sense in setting up independent traffic study investigations and ensuring that there is sufficient correlation between results to provide an assurance that the commercial risk is well understood.

Routes can radiate to and from a hub (most 'national' carriers) or a large airline might have several hubs (typical US 'mega-carrier'). These are hub-and-spoke route structures and are the most common route structures in use today. In the pre-jet days, when long-haul travel was a laborious affair, there were stopping points en route, creating a so-called linear route structure. These are almost defunct nowadays. One reason for wishing them goodbye is that scheduling the use of seats on individual sectors is a nightmare.

Variations on hub-and-spoke that are commonly encountered include the 'round robin'. This is a service where there is an intermediate stop, such as a route from A to C via B. If B and C are relatively close the return trip might not be conducted back via B, but direct from C. A further variation is most frequently encountered when a new 'hub' is being established, which will serve destinations already visited from an existing hub. In this case the aircraft flies from A to destination B, then from B to the new hub, then back to B, and finally returns to A. All the crewing and maintenance resources might be at A, and thus the new hub's potential is tested with minimal



6.2 Route structures and scheduling variations.

additional capital or infrastructure investment. This is called a W-schedule. These are illustrated at Fig. 6.2.

The most significant way that airlines have stimulated demand is by stimulating the use of its main base as a transfer hub. This means attracting those passengers who fly from B to F via their own base, location A. In the circumstances being considered here the belief is that B to F via A is a travel option that will appeal as much as flying from B to F directly. Two issues will influence the passenger's choice – time and cost. This has been discussed in Chapter 1, where the interest was on the comparison of properties of different ways of serving locations in a simple nine-airport system.

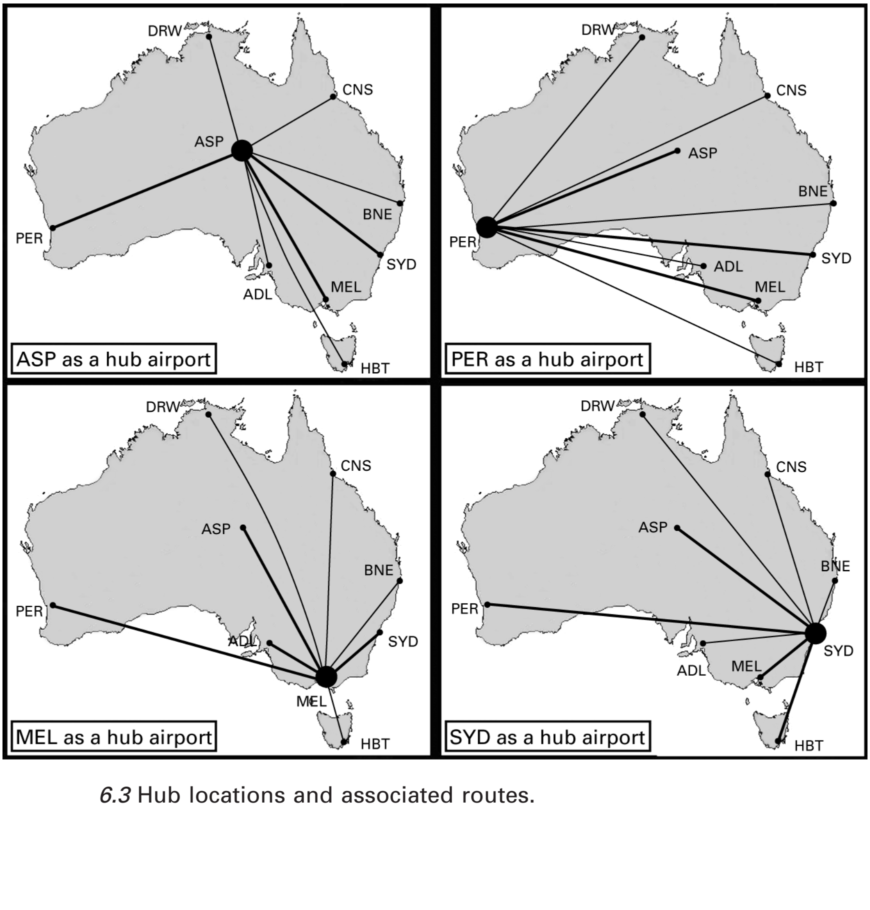
Route planning requires that suitable routes are selected, that the right aircraft type is selected and that a schedule is constructed that will provide the transfer passenger with convenient connections. It is not 'routes' alone. A further caveat is that, ideally, the destinations should be at similar distances (or roughly multiples thereof), as in operational terms the similar flight times will create interlocking schedules.

As an example of how interesting, and sometimes surprising, the results from a hub analysis can be, consider the idea of offering hub-and-spoke routes in Australia. If one looks at the geographic and distance-related attractiveness of routes in terms of avoiding acute angles between services and getting a small spread in route distances, the best hub location to choose is Alice Springs, in the centre of the continent. Analysing Australian airports using a traffic model to generate expected demand for direct services between the airports shown and five other Australian airports (Adelaide, Brisbane, Hobart, Cairns and Darwin), and then using the same data as a reference to assess the percentage attractiveness of hub services considering Perth (PER), Alice Springs (ASP), Melbourne (MEL) and Sydney (SYD), the apparent case for Alice Springs soon collapses. Maps are shown in Fig. 6.3 and the traffic data are presented in Table 6.2.

The highlighted numbers in the table represent the best result (maximum or minimum appropriately) with regard to the parameter on that row. The combined passenger data show the number of passengers that would use

Table 6.2 Statistics assisting in the selection of a preferred hub (the best results are indicated in bold)

Hub airport	ASP	PER	SYD	MEL
Route data (km)				
Average stage	1817	2882	1591	**1539**
Standard deviation	**365**	527	1026	961
Basic passenger data (passengers/week)				
Direct services	14 895	16 342	**28 583**	26 902
Maximum hubbing potential	26 055	7436	31 759	**34 458**
Combined passenger data (passengers/week)				
Direct + (100–70%)	30 264	16 342	46 825	**50 976**
Direct + (100–60%)	34 257	16 723	**54 656**	53 305
Direct + (100–50%)	36 369	16 723	55 881	**58 238**



6.3 Hub locations and associated routes.

services that the angle between services has suggested could attract either 70% or more, 60% or more or 50% or more of the direct service expected passenger flow.

In terms of which airport accumulated the highest number of best results, Melbourne seems to be the best airport, but it would be a brave analyst that suggested that it has a clear advantage over Sydney. The two are very close indeed. Alice Springs, meanwhile, shows the expected advantage in terms of a low standard deviation and it picks up, proportionally, a lot of transfer traffic, but there is nowhere near as much passenger demand as there is at the two large cities. Perth is revealed as the most remote city to all the other communities and therefore the least attractive hub location at which to perform domestic service transfers in Australia.

This is an example of a systemic process model. It has tracked attributes of the service characteristics of each possibility using a consistent analytical approach and concentrated on factors that can be related to efficiency and effectiveness. It is not dissimilar (although certainly simpler) to the kind of analyses that are conducted routinely by airlines, to determine their future route planning strategy. One example of its simplicity is that the distance between each set of airports has been treated as a set of direct (or great circle) distances, whereas aircraft often fly longer distances, as they use routes that are based on radio navaid locations and are not direct. When the overall distance between airports is large this is not a significant issue, but viewing smaller distance operations in Europe would be very different. Nevertheless, as an example, it shows that selecting a 'hub' is a vital consideration.

Where the airline's operational region is a much less self-contained community than in the example, as is the case in Europe, the route analysis is more complex. For example, considering Western European destinations that are near the Eastern European boundary and ignoring demand from outside the target region will fail to recognise demand to/from Eastern European locations that travels overland to use the airline's services.

The amount of such demand is unlikely to be the same over time, and in the example quoted demand tended to rise considerably as the 'border' countries became European Union (EU) members. This is an example of how any traffic forecast will be valid at a point in time but will then need to be updated, with the assumptions incorporated within them fully explained before an airline plan is built upon the potential they express. Route development will consider the social, economic and political factors that influence demand, showing that traffic forecasting is much more than just a set of mathematical equations. The judgement that is exercised in creating a forecast can be crucial to its realism, and thus its value to the user. It is the application of such skills that often can give an airline an edge over a competitor.

Be aware that once they reveal their hand by publishing their new destinations list, an airline effectively loses the element of surprise. It should be no surprise, therefore, to find that traffic forecasts and route development plans are invariably treated as commercially sensitive information.

6.5 Airline fleet planning

Once the routes are recognised, a key decision is getting the right aircraft for the job. Among aspects that have to be considered are:

- The aircraft should be large enough to offer a reasonably competitive seat-km cost.
- However, it should not be too large as service frequency must be acceptable.
- It should be fast enough to offer a competitive block time.
- It must be comfortable enough to win passenger acclaim. Some issues have already been described, but these are not universal.
- It must be able to fly the necessary range, with adequate payload, using the runway(s) available, in all likely weather conditions and at all service destinations.

The aspects of aircraft and airline operational planning that determine the detail within these areas of interest have been introduced in earlier parts of the book. The complexity therefore of the task of finding the best-suited aircraft type is clearly more difficult that just simply getting 'ticks in boxes'. In most airline evaluations, and because of competitive pressures, seat-km cost is the most influential selection parameter. The second most important parameter is usually payload–range. The rest are less important, but they are still critical to getting the quality of service, and in some cases, such as when a constrained hub airport with a short runway is used, that issue could climb to the top of the pile.

In evaluating an aircraft, an airline will generate data on stage lengths and loads (largely passenger numbers, but there could be significant amounts of freight to add), and look for associated payload–range and operating cost data. The former is almost set by the design, the issues governing payload and range trade-off having been explained in Chapter 5. The operating cost is subject, to some degree, to airline discretion, because it can be influenced by:

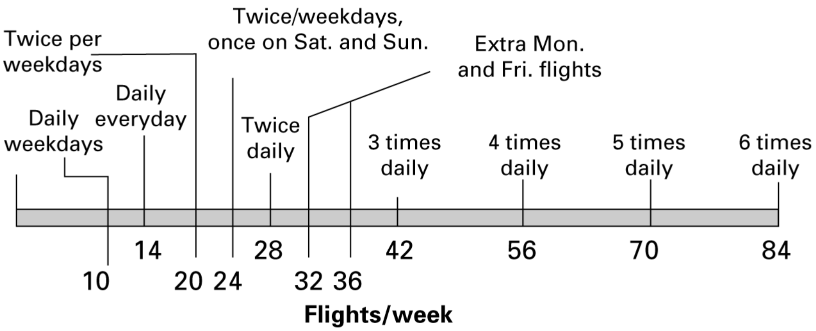
- annual utilisation
- variations to indirect operating costs, attributable to organisational issues
- aircraft seat capacity.

Note that although a quasi-static view of fleet planning has to be taken, an

actual airline evaluation will use forecast data that will incorporate assessments of traffic change over time. Thus, the expectation of rapid change could mean that it is necessary to buy slightly oversized aircraft and to make adjustments, perhaps in aircraft seating arrangements, as the airline expands. In dynamic fleet planning the number of aircraft needed year-on-year will be predicted, and an order for examples of a type is placed with the manufacturer. Then options are added, with preferred dates of conversion to orders. If the market shapes up differently to what was expected, requests will be made for options to be exercised early or deferred. An airline and an aircraft supplier, and even some of the major subcontractors, such as aeroengine manufacturers, are often teams that are closely knit.

6.6 Annual utilisation and aircraft size

The criticality of annual utilisation to operating cost has already been addressed. The point has been reached where this topic becomes a part of the quest for getting the right sized aircraft for the job, so it is a topic that can also be associated with payload–range capability, which an airline, ideally, would not wish to be the case. Size, in terms of nominal passenger capacity, has an impact on service frequency. In business traveller operations a daily out-and-back service is the minimum that customers will tolerate. If it falls below that frequency, the passengers are likely to find an alternative route, even if it is not direct. Thus, the number of flights per week per service that are used in planning a fleet determines a lot. A simple guideline is the numerical data shown in Fig. 6.4. This shows that 10 flights weekly is the minimum for an out-and-back service on weekdays only for a regular airline operation. This is not always achievable when a service is new or the destinations are a long distance apart. The question will arise, in such a case, as to whether a smaller-capacity aircraft is available, and will suffice, or whether a round-robin or W-schedule solution should be used.



6.4 Daily and weekly flight frequencies.

The opportunity for airline planners to fine-tune their options is considerable. Assume that an airline forecasts a demand for 500 passengers, one-way per day on a route. They can accommodate this in several ways:

100-seat aircraft 5 times daily	=	100% load factor
100-seat aircraft 8 times daily	=	67% load factor
150-seat aircraft 4 times daily	=	84% load factor
150-seat aircraft 6 times daily	=	56% load factor
250-seat aircraft twice daily	=	100% load factor
250-seat aircraft 3 times daily	=	67% load factor
500-seat aircraft once daily	=	100% load factor

The load factor (percentage of seats filled) has been calculated on the assumption that demand will be unaffected by service frequency. This is not true. A more frequent service will offer more flexibility, to all categories of travellers, and will be more appealing. The operating cost per seat will also be a function of the size of aircraft. For example, the larger aircraft (assuming it is as well utilised as a small aircraft) will offer more opportunity to sell seats at a lower price.

This is where a book has great difficulty in showing how such decision-making is handled in a business. A written explanation has to treat decision-laden topics in a sequential manner, but in reality decisions are taken in parallel with others in the airline planning chain of command. There is plenty of scope to accommodate an iteration of variables such as fares, seat numbers, service frequency and consequently aircraft size. In systems thinking terms this has been identified as 'joined-up' thinking in recent years, but here is evidence that it is not a new idea.

There are many innovative solutions, some of which have passed the test of time and others that have not. A simple example of a ploy for providing better 'value' but still having flexibility in an aircraft is to have a cabin where triple seats can become double seats with a central table, simply by folding down the seat back.

When seat requirements do not match frequency, a common solution is to use different aircraft types – smaller aircraft on the 'thinner' routes – so that a consistent frequency of service is maintained. This option is only possible in large airlines, where large common fleets offer such advantages as scheduling flexibility, but they have become more common in recent years. A solution for a large carrier is often to 'franchise' the 'thin' routes to a regional aircraft operator. To reduce variable costs on the small aircraft, they might be persuaded to operate with a common livery, to have common flight codes and to use the parent company's ticketing, reservation and advertising capabilities. The impact this has on indirect operating costs is addressed in more detail later.

Table 6.3 Surveyed range of seat pitch dimension on several airlines (Source: Business Traveller 2007)

Seat category	Sample	Min–max pitch (cm)	Average cm (in)
First	28	90–231	197.0 cm (77.6 in)
Business	126	86–198	140.8 cm (55.4 in)
Economy	159	76–94	81.5 cm (32.1 in)

6.7 Seating arrangements

In terms of seating, aircraft can be categorised under two broad headings: wide-body (or twin-aisle) and narrow-body (or single-aisle). Single-aisle aircraft can have between two and six seats per row, with the aisle near to the centre (maximum headroom) portion of the cabin cross-section. A six-seats per row single-aisle layout will have three seats either side of the aisle. This is the maximum number of joined seats that passengers will expect, but the overriding driver might be from safety regulations, because in reviewing the aircraft during design, limits will have been imposed on numbers of adjacent seats and the distance to an exit from any point in the cabin. The aim is to minimise the likely time to evacuate the cabin. These criteria are applied to all aircraft, and on a wide-body aircraft they usually require that there are two aisles, and generally impose a limit at 10 seats per row. Multi-deck aircraft are subject to additional constraints, but these apply, so far, only to the Boeing 747 and Airbus A380.

Seat size can vary greatly too. The data in Table 6.3 illustrate the great variation in seat pitch that can be experienced throughout a number of airlines surveyed in 2007.

There is little reason here to delve into the relative values of having more or fewer toilets, or bigger or smaller galleys. Nevertheless, these are issues on which an airline will make considerable judgement; while they are not parameters that routinely will determine whether or not a passenger buys a ticket, the airlines know that they are factors that will impact service quality aspects that especially frequent travellers will take into account. Because these parameters influence choice, they are significant.

6.8 Indirect operating costs

There are several airline ownership models, ranging from one where everything that is used is owned and where staff are employed to conduct everything 'in-house' (which is the way it was done by everyone until the 1960s or so) to one that leases as much as possible and subcontracts as much labour as possible (which, to an extent, is the way that airline businesses are more often configured nowadays). The former is the model that ensures

greatest control over labour, but it is inflexible. Thus, when circumstances change, the airline often has an inertia that sees expenditure maintaining a steady course while the revenue is plummeting. By using subcontracted labour the airline has all the components more loosely federated (in a business sense) and has a greater capability to redirect resources, and thus to tailor expenditure and revenue. This promises a better likelihood of survival in a turbulent business environment.

Some permanent employee positions are unavoidable. These include those associated with the airline's operating licence, an executive-level 'board' to conduct strategic management and individuals who will contribute to continuity of purpose at all stages below executives – ranging through middle management, supervisory and 'production' levels. It is usual to classify employees in categories that can be associated with roles, such as administration, finance, flight operations, station management, and so on. However, take a list of airlines and their employment data from any reputable source and try to analyse it objectively; the chances are that you will find little correlation in the way they apportion staff to various functions or duties. There is tremendous diversity in the kind of operating models that are used.

E-commerce has been used to reduce indirect costs in almost all airlines, but the most significant examples have been in low-cost airlines, where indirect costs were, initially, only a fraction of those of traditional airlines, largely as a result of internet booking. Various passenger categories will enumerate different benefits and dis-benefits from such developments, and the answer as to what is right or wrong is not easy to distil. The established airlines have tended to take a leaf from the low-cost operator book by opening internet bookings, for example, but they often retain the traditional travel agent and telephone enquiry and reservation options, especially for business travellers.

6.9 Aircraft: buy or lease

In the last few decades it has been more commonplace for airlines to avoid the capital expenditure involved when aircraft are purchased directly, by leasing their fleet from an intermediary leasing company. The theory is simply that, as aircraft are very expensive, they lock money in assets. If the aircraft can be leased, the lease costs can be repaid from revenue and the need to borrow capital will be reduced. This minimises capital investment and where assets are available it may allow alternative investment opportunities to be explored that will diversify and strengthen the airline's portfolio.

Thus, if an aircraft is leased, the following benefits should accrue:

- On an annual basis, provided the leasing agreement is long-term, the lease option is the cheaper alternative.
- The annual repayment cost (and the same is true whether a lease or a purchase agreement is struck) diminishes as the repayment period increases.

The main benefit that accrues if a fleet is purchased rather than leased is that there will be an asset on the balance sheet. This adds value to the firm, but it is an inflexible asset, and that might not be a great advantage.

Leasing does offer the chance, therefore, of reducing operating cost, only slightly, but perhaps crucially, because it can impact the airline finances appreciably. One reason why a leasing company can provide aircraft at relatively favourable terms is that they will bid for a larger quantity of production slots than most airlines and thus have a special relationship with the aircraft manufacturer. They will often agree to take 'spare' slots between promised deliveries, and on both counts they are able to negotiate a discount from the builder. Nevertheless, some airlines, and especially the newer breed of low-cost carriers that have single-aircraft type fleets, can buy from the builder in bulk, and if they approach the manufacturer at the right time (with regard to their own costs) they will be able to negotiate a similar discount. Large airlines sometimes lease part of a fleet and buy the remaining aircraft, so retaining a degree of ownership and incorporating some flexibility.

In reality, leasing and purchase deals can have many more complex characteristics. Although the actual prices of aircraft are published regularly in some journals, the acknowledged price is likely to represent the highest price that any client would have to pay. Having now explored the synergies that link the aircraft manufacturer and the operator, the scope for flexibility is much clearer.

6.10 Revenue generation

After costs, comes revenue. Fares are not the sole source of revenue for an airline, but this is the most significant income source. The commercial specialists in an airline coordinate with route and fleet planners, determining the pattern of frequency of service, seats configuration, the impact of a lease/purchase deal, etc. Based on the costs they can attribute to these decisions, they declare a yield target for each service. Yield is the amount of income that is necessary to cover costs per seat available. Hence, if there are 100 seats available and 75 are sold at £40 each, the income is £3000 and the yield is £30 (per seat available). If the yield target was over £30 this would be a loss-making route, but if it was below £30 it would be a profitable service.

Yield management – the tailoring of fares to ensure that yield targets are

exceeded on as many services as possible – plays a large part in determining what fares the airline will charge. The general belief is that the lower the price of a ticket for a given service, the more passengers will be attracted.

If the operation is between two locations with well-developed economies, there is likely to be sufficient disposable income for that expectation to be true. However, in less well-developed economies, the availability of seats is irrelevant if the population does not have the disposable income to spend on travel. In the latter case, no matter what fare is set, the aircraft will fly almost empty.

Even in situations where demand is buoyant, eventually demand will saturate. If the service is between two small communities, there will be a limit to the frequency of service that can be operated with a given aircraft type, but the smaller the aircraft the higher the frequency of service that can be economically sustained. This is all based on the idea that seats are sold at a single price, which is a great simplification, because airline marketing strategy is usually based on offering seats at a range of prices. For example:

- A low-cost carrier might demand that a late-booking passenger pays over ten times the price for a seat as the early-booking passenger.
- On a 'traditional' carrier, as has been hinted already, the cabin might be divided into compartments (on long-haul operations, first, business and economy cabins are commonplace), and the price of the seats, while again not immune from a time-before-flight variation formula, will reflect the relative quality of service offered in each cabin compartment.

Access to seats at two different fares will always favour the lower fare, so low fares are usually released early in the booking period (which might commence several months before a flight is due to be operated) and the price will increase as the date of operation approaches. This is generally true, but not universally applicable, as where a carrier has a desire to pull market share and has little regard for profit – more an interest in beating the competition into submission – fares may even fall, provided seats are available. This is a risky and relatively rare strategy, but it is an example of financial viability being more important than profit alone. If a competitor will split the market and limit the ability to make a commercial success, then if there is a belief that the competitor is less able to sustain a period of losses, an airline may choose to operate below its own margins.

6.11 Computerised reservation systems

The flexibility that is associated with fares in aviation was not always there. In the 1950s and 1960s there was a tendency for all airlines that offered licensed air services to be members of the International Air Transport Association (IATA), and it was IATA that set the fares. A few companies,

often referred to as 'independent' airlines, operated outside of this regime, but they accounted for a minute proportion of all operations and they were unable to enter into cross-carrier booking. Two IATA-member airlines could share a fare from A to B via C, where the two carriers flew A to B and B to C on their respective route networks, but where no one offered A to C direct. This was called pro-rata fare setting and is still in place today. The process is often called clearance, and the airline personnel who handle the process are the revenue-accounting department.

Fare structures came in for a major overhaul, however, when computerised reservation systems (CRS) were introduced by the major airlines in the late 1960s. Initially it was based on the airline's own needs, and the way it could be accessed was two-fold. A customer could enter a local shop (the airlines had their own booking offices in all major towns) and book a ticket through the airline clerk or telephone an enquiry. As investment in CRS began to grow, airline offices disappeared, as they were expensive to run. Now all the airline clerks were concentrated into what we would regard as a 'call-centre' today, and they would process requests from customers or travel agents by telephone. If the enquirer was a travel agent, they could book a ticket for a client and they took a commission.

In addition to changing the customer interface, the most significant operational influence of the CRS was the way it allowed seat sales to be monitored. It was a long overdue advance for airline sales staff, who had long yearned to be able to 'manage' seat sales. They desired not just to offer seats and have happy passengers, but to ensure that all seats would be sold – on an individual flight-by-flight basis – and, crucially, at the highest price that people would pay for them. This was the beginning of the 'yield management' process.

Initially a variety of ticket options were used, introducing terms that have characterised the changes that were occurring within the business. These included:

- *Advanced-purchase excursion (Apex) tickets*. Basically, this was to buy well in advance and get an economy ticket at discount. Airlines put very tight controls on ticket validity, but this still appealed to those on long-haul flights visiting friends and relations (VFR passengers).
- *Business class*. The full economy fare passengers objected to having discount passengers on the same seat rows, so the airlines introduced a better quality service. Modern business class equates to the old-time economy – modern economy is a lesser quality product (in terms of ticket validity). Later, better seating (greater width and pitch) became the norm for business class.

In the 1970s, the number of fare categories applicable on a long-haul flight

grew rapidly, from a basic two (with some variations) to in excess of 20. As the decade wore on, the short-haul flight scene changed equivalently.

An associated initiative was the frequent flier programme (FFP). This was a simple way of giving recognition to a loyal customer. The customer's FFP membership card helps airport counter staff to recognise passengers whom they should regard as commercially more important than others (cards are banded as silver, gold and platinum). Alternatively, or additionally, by accumulating 'air miles' the customer gets a bonus that is once again recognition of their loyalty. Some 'air mile' schemes extend into the wider retail market and can be accumulated in non-aviation activities.

By the mid-1980s there was a particularly serious operational complaint, which was that the CRS was often 'biased'. The oft-quoted case was that if a customer used a travel agent, who officially was 'unbiased', to research flights between A and B, the probability of a booking being made that was not in the top six listed (typically the first screen listing) was very low, so the airline that was providing a CRS service would thus put its own services at the top of the list in its own system and win an unfair advantage. As not all airlines could afford a CRS, the larger airlines offered access to travel agents via their own CRS, and they were in a powerful position to monopolise demand on the busiest routes.

IATA, acting as an independent body, worked with anti-trust law enforcement agencies to generate rules that were 'fairer to the customer', and these apply to all CRS software programs. However, the airlines have a neat side door: they often get their flights quoted many times through having code-shared flight numbers. This is also regulated as tightly as it needs to be, again to maximise the public's ability to get good value for money. In general, on a modern CRS flights will be displayed according to best times (using user-declared criteria) and then lowest fares, and only then is the airline taken into account.

The most significant recent development in this field has been internet-linking, allowing customers direct access to the CRS from their own home, or at any time and anywhere if they have an appropriate terminal with an internet link. However, since the mid-1980s the presence of CRS has not been the most important issue, insofar as software-based processes have evolved on the back of the databases with the system. These are 'yield management' systems. Their underlying principles deserve study as they probably share characteristics with many future business developments. As they aim to be 'fair' to passengers, they have to acknowledge that they are a business instrument that the airline is also using to enhance its own competitiveness.

Table 6.4 Hypothetical fare and seats demand relationship

Fare ($)	Seats sold
0	100
20	100
40	100
60	100
80	100
100	100
120	80
140	62
160	46
180	32
200	20
220	10
240	5
260	2
280	0

6.12 Yield management

For every route there will be a yield target, which has been determined from the airline's operating philosophy, choice of aircraft type, fleet size and utilisation, and the many other influencing issues. Yield managers must attract rather than deter customers, so they try to maximise load factor. However, they must expect to be mandated to ensure there is the flexibility to accommodate high-yield as well as low-yield customers, although the former are risky in terms of their propensity to book late and even not show for a flight. These are difficult objectives to reconcile.

Consider a hypothetical service operated by a 100-seat aircraft, where, with a single fare, the prognosis is that demand will follow the fare, as shown in Table 6.4. A zero fare operation might fill the aircraft, but revenue would be zero. Likewise, if the fare was very high, $280 shown, the situation is the same in terms of revenue because the demand is now zero. Somewhere in between is either a better solution or a range of better solutions, and the yield manager is expected to identify and keep that range and keep route sales performance in an acceptable band.

In the example described, the revenue, load factor and yield values that emerge from the anticipated demand are shown in Table 6.5.

If an operating cost assessment has set a yield target of $40, there are two limiting solutions. Selling all seats at $40 each promises to recover costs. Alternatively, at about $205, while only 19% or so seats are sold, the same yield target is achieved. Anything in between is likely to prove to be a profitable operation.

In such a case the yield manager can be expected to release seats

Table 6.5 Demand relationship viewed as revenue and yield data

Fare ($)	Load factor	Revenue ($×1000)	Yield ($/seat average)
0	100	0	0
20	100	2.0	20
40	100	4.0	40
60	100	6.0	60
80	100	8.0	80
100	100	10.0	100
120	80	9.6	96
140	62	8.68	86.8
160	46	7.36	73.6
180	32	5.76	57.6
200	20	4.4	44.0
220	10	2.2	22.0
240	5	1.2	12.0
260	2	0.52	5.20
280	0	0	0

Table 6.6 Yield manager's fare and sales allocation

	Fare ($)	Allocated seats	Seats sold	Revenue ($)
	10	10	10	100
	20	15	15	300
	40	20	20	800
	60	20	20	1200
	80	10	8	640
	100	10	6	600
	150	10	5	750
	200	5	3	600
Total		100	87	4990

gradually, starting with low fares, and letting the fare rise progressively, so long as demand is not receding. When the latter happens, if there are still seats to be filled, the fare will drop again. For the hypothetical service already considered, if the yield manager allocates seats as shown in Table 6.6 and sells seats in the quantities shown, the revenue shown is generated.

This is a solution where 87 seats are filled (so load factor is 87%), where the revenue is $49.9 per seat, handsomely exceeding the $40 per seat yield target, 45 passengers paid below or at the operating cost per seat and 42 passengers paid more than the cost. This example is not untypical of the solution that is applied in many modern short-to-medium haul operations. However, every flight is different. What happens between A and B at one

time of the day might not be the same as what happens at a different time, on the same day or at a different time of the year, and so on. It is the yield manager's responsibility to release seats according to a price strategy that will also distribute passengers across the less-favoured flight.

The principles have now been stated, but in reality the quest for business in the commercial market can be much more demanding than the example suggests. The most demanding aspect of passengers who pay a 'full fare' is that the terms of the ticket give them the right to change their booking whenever it suits. They can be booked on a flight, be detained on business and miss the flight, and then arrive at the airport and request a seat on a later flight. It is a right they have purchased. They are a 'no-show' on one flight and a 'go-show' on another. If business has taken an unexpected turn, they can decide to fly elsewhere and then return via a different route, securing new tickets. To accommodate their discretion and to ensure that load factors do not tumble as a consequence, an airline can 'overbook' passengers, meaning that they will issue a total number of tickets that exceeds the number of seats on the aircraft. Statistically, they will expect the demand to redistribute itself such that the chances of a passenger being stranded are acceptably small. This is policy and the resolution of overbooking is an operations issue.

The effort needed to conduct yield management is considerable, and in a large European airline with 100 or so aircraft, flying long-haul and short-haul, there can be 400 flights per day or close to 150 000 flights available at any one time on a one-year-ahead booking system. The yield manager uses the CRS infrastructure to look under the surface for unusual sales profiles and to draw attention to where decisions need to be made.

6.13 Integrating service quality into the revenue-generation process

The dichotomy that vexes the astute manager's mind is that 'overbooking' to protect against 'no-show' and 'go-show' eventualities is tantamount to taking risk with customers. The yield management description has shown that these are often late-booking travellers, which means that they are the people that the airline depends on to make a profit, and thus if they do not roll up the service runs only marginally, in financial terms, and may be even at a loss. The airline has to be 'kind' but cannot afford to foot the bill.

The way this is handled in planning is to appreciate that the average load factor is just that – an average over a number of events. On 50% of occasions the load will be higher. If the average load factor is 60%, the chances of a load reaching 100% is less likely than if the average passenger load factor was 70 or 80%. A technique is needed that will determine what

proportion of passengers are likely to be turned away, either on enquiry or at the gate. One technique that provides some useful insights into equivalent service quality related issues that have yet to emerge is a technique called 'spill factor' analysis.

Spill factor (an analysis technique developed by Boeing in the 1960s) assumes a statistical distribution of demand and presents a relationship between the average load factor and the probability of having a load factor that is above or below this value. It is suited to assessing the likelihood of a 100% load factor, and thus is a means by which capacity limitations can be related to service quality issues. The technique is as follows. To measure 'spill' it is necessary to derive, or predict,

- the mean passenger load (μ)
- the standard deviation (σ)
- the coefficient of variation (k)

$$k = \sigma / \mu$$

The kind of issues that have to be tracked to 'understand' why demand varies are quoted to include:

- seasonal (winter/summer)
- daily (weekdays/weekends)
- time of day
- holiday (can be seasonal related, but especially 'peaky').

Boeing comment that demand will be different in different directions, so A to B is not the same as B to A. Their analysis also suggested that $0.2 < k < 0.4$ for airline routes (but that might not be so true 40 years down the line) and that route passenger data can be analysed assuming the distribution of passenger loads as a Normal distribution. Statistical theory suggests that, because passenger numbers are discrete and cannot have a negative value, this must be wrong; the distribution should be binomial or Poisson. However, it can be shown that in certain ranges of values of mean and standard deviation, the normal, Poisson and binomial distributions become very similar. This is true for most airline passenger load applications unless the aircraft is very small. It is recommended that when analysing operations with a 40-seat size aircraft and smaller, analysis should assume a binomial distribution.

Spill factor theory suggests that if the aircraft capacity (maximum number of passengers/flight) is C, the expected load can be expressed in the following way:

$$\text{Expected load} = (\mu - C)\, F_0\, [(C - \mu)/\sigma] - \sigma\, f_0[(C - \mu)/\sigma] + C$$

where $f_0(x)$ and $F_0(x)$ are expressions from normal distribution probability

Table 6.7 Example of spill evaluation

Passengers spilled	Expected load	C
5.58	44.42	50
2.73	47.27	57
1.17	48.83	64
0.41	49.59	71
0.12	49.88	78

tables. $F_0(x)$ is the accumulated area across the distribution and $f_0(x)$ is the normalised value in the distribution.

Example

$$\mu = 50 \text{ passengers/flight}, \quad \sigma = 14 \text{ passengers/flight}, \quad \text{hence } k = 0.28$$

If $C = 78$ (maximum number of passengers/flight)

$$\begin{aligned}\text{Expected load} &= (50 - 78)\ F_0\,[(78 - 50)/14] - 14 f_0\,[(78 - 50)/14] + 78\\ &= -28\ F_0(2.0) - 14 f_0\ (2.0) + 78\\ &= -28\ (0.9773) - 14\ (0.0540) + 78\\ &= -27.3644 - 0.756 + 78\\ &= 49.88 \text{ passangers/flight}\end{aligned}$$

$$\text{Passengers lost (or 'spilled')} = 50 - 49.88 = 0.12 \text{ passengers/flight}$$

If this evaluation is conducted for several capacities, a pattern emerges that seems logical but would be difficult to justify otherwise (see Table 6.7). Hence, a logical conclusion is shown, that increasing capacity reduces the possibility of 'spilled' passengers on any service.

It is also possible to use passenger spill data to estimate the cost/revenue benefits for an airline. The example in Table 6.8 assumes that the loss of one spilled passenger is \$200 (route fare) and the extra operating cost of one added seat is \$50.[1] From the above analysis it can be concluded that:

- It is well worth adding 7 extra seats to the available capacity.
- It is not worth adding 14 or more seats.

The value of spill analysis is clear when it is used to estimate the 'spilled' passengers per flight and to look at it as a proportion of passengers boarded.

[1] This is very hard to estimate. If a seat row is added by tightening seat pitch, the cost could be almost negligible. The value used here reflects the situation if a different-sized aircraft is substituted.

Table 6.8 Spill evaluation results

Capacity	50		57		64		71		78
Capacity cost (base)	$350		$700		$1050		$1400		$1750
Incremental cost		($350)		($350)		($350)		($350)	
Spilled passengers	5.58		2.73		1.17		0.41		0.12
Incremental spill		2.85		1.56		0.76		0.29	
Incremental revenue gain		$570		$312		$152		$58	
Revenue gain less cost		+ $220		– $38		– $198		– $292	

If the proportion of spilled passengers exceeds 5% of the aircraft seat capacity, the possibility of a passenger being refused a seat (not boarding) will be greater than once in every 20 enquiries. This can be treated as a threshold that will cause business users to look at competitor's operations.

By using the analysis in this way, an assessment can be made of whether the trade-off in getting a high load factor with improved revenue (short-term benefit) will lead to disappointment among passengers (long-term dis-benefit), leading to a haemorrhaging of demand in due course. It is the application of a process of this nature that leads analysts to assume the load factor pattern shown when a three-class cabin was analysed earlier in the chapter (which assumed an 85% load factor in economy, 65% load factor in business and 45% load factor in first class). The chances of a late-booking first-class passenger being refused a seat or of ever being overbooked are negligible. It is privilege, however, that comes with a sizeable price tag.

6.14 Marketing the seats

The concern in these notes is largely in planning as the mechanisms that will be used to sell seats (marketing) is not deeply considered. The airline will pursue a policy in ascribing service quality criteria at the planning stage that will reflect the way they will market the products, or airline 'brand'. Demand can be tailored by successful marketing policy, and in yield management the impact of marketing initiatives can be monitored. Thus, real-time tactics can be used to fine-tune the revenue-generation process. There is no reason why, within the limits that a mature use of the capacity variations that a good revenue-generation policy offers, a success cannot be extended, or enhanced, or a failure mitigated against.

This is a concern that affects how a company manages the sale of a perishable commodity. This situation, and a process for managing it, will re-emerge in later chapters. It is difficult to overstress how important an example this is in terms of the way it can be read across to other service providers in the aviation business, whose contribution is yet to be considered.

6.15 Airline scheduling

The scheduling process is where many of the implications that stem from the earlier work come together. The scheduler must ensure that each aircraft is allocated to perform the services planned. The information needed is:

- routes to be served
- time-zone of each destination relative to the hub
- number of flights/week per route
- block time on each route
- number of aircraft in fleet.

The scheduler allocates each aircraft to each service, taking into account:

- turnround time: the minimum time needed to empty and refill an aircraft when it passes through an airport
- where aircraft will be overnight, as not all will necessarily be at the hub on every night of the week
- the time of the day when passengers will want to fly.

The turnaround time is governed by logistical and aircraft servicing needs. Therefore, the longer the preceding flight, the more likely it is that the aircraft will need more time to refuel, to clear rubbish from the cabin, to re-stock the galleys, etc. The agreement for a given turnround time might also hinge on some airport policy issues, with fast turnround bringing substantial benefits when it comes to agreeing airport charges. This is a negotiable issue and has become a valuable bartering chip in some airline/airport agreements.

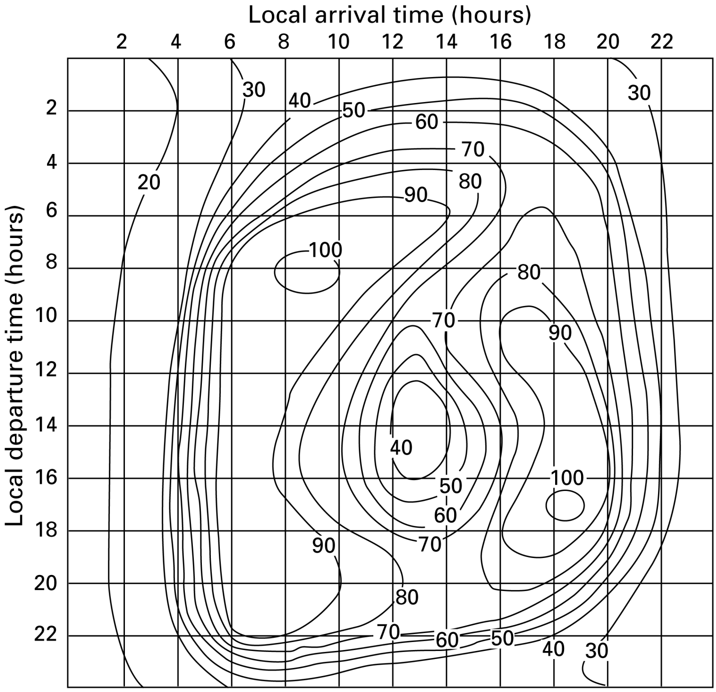
The choice as regards whether an aircraft conducts an overnight stay at an outstation can hinge on passenger demand and time-zone influences. Where a route structure has a considerable east–west dimension, the best operating plan is to start aircraft at the east as the sun rises and to travel, almost keeping with the rising sun in high latitudes, in order to land at an early local arrival time. It does not work 'both ways' – heading east it is necessary to do it in daytime or if the flight has a long duration (typically, in excess of six hours) to do it overnight. If a route does not have a high service frequency (in excess of 28 flights per week) the choices can be stark; if a daily schedule is to be created there are only two flights daily in each direction to plan. The passenger attraction of certain times of the day is less likely to be as influential when a more frequent service is provided. These are issues that might lead to re-evaluation of the aircraft size/service frequency trade-offs introduced by the fleet planner.

There are no hard and fast rules as to what times of arrival and departure are likely to win the seal of approval of passengers. An oft-used illustration in textbooks shows two humps on a 24-hour time plot, and suggests that

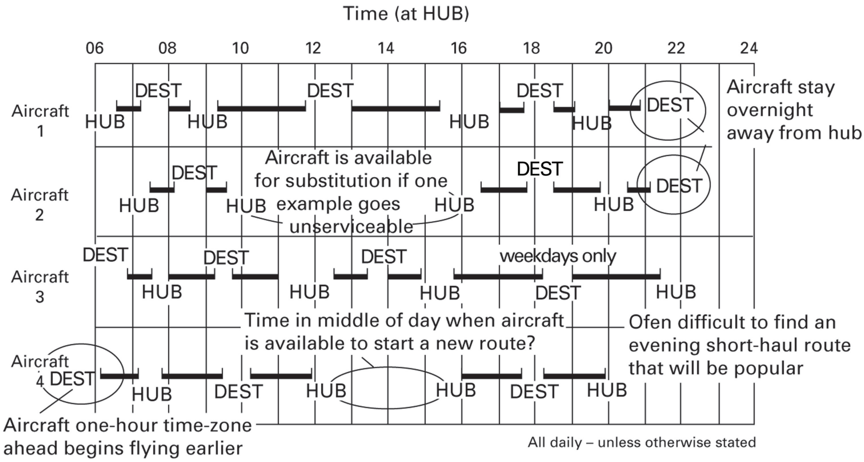
there will be a preference for flights in the early morning (for people flying 'out') and in the evening (for people 'returning'). This is true in business operations over a limited number of time zones, for example in the US 'corridors' (Boston–New York–Washington and San Francisco–Los Angeles–San Diego) and across most of Western Europe. It is not so true of US transcontinental flights or for long-haul flights, such as between Europe–North America and Europe–SE Asia.

Figure 6.5 was derived from an analysis of timetables in the mid-1980s. With the assumption that combinations of flight departure and arrival times (local at the departure and destination points) illustrate what airlines have found can equate to attractive schedules, it can be treated as a passenger attractiveness plot. The outcome is essentially only true for business demand, as leisure (charter) and no-frills carrier demand characteristics are not so pronounced, although they do have to take account of diurnal demand patterns. (A proposal is that the pattern still exists, with less pronounced valleys and peaks, but this has neither been investigated nor validated at this point in time.)

As aircraft are allocated to routes a set of aircraft schedules will emerge, and the departure and arrival times have a degree of justification. The daily aircraft schedule for a small fleet can be generated readily, but for a large



6.5 Time of service and passenger attractiveness.



6.6 A hypothetical airline schedule: four aircraft serving four destinations from a hub.

fleet the task can take a considerable amount of time. Computers can take some of the guesswork out of scheduling, but almost all airline schedulers perform adjustments to computer-generated flight times before they submit flight numbers and times for incorporation in the airline's timetable and CRS database. Some of the issues that human interference adjusts for are:

- early departures, and distributing aircraft in 'departure waves'
- late arrivals, and distributing arrivals in 'arrivals waves'
- introducing the chance for aircraft to switch schedules, or built-in 'robustness'
- ensuring that aircraft at the end of a day are where they start the *next* day.

6.16 Evaluating success

Having navigated through an airline planning process that has considered route planning, fleet planning, yield management and fleet scheduling, the chapter arrives at the point where, although all the participants in the process should be able to justify their contributions, no one has yet looked at the consequences against criteria that will relate to the objectives of the airline itself. In particular, by now there should be enough evidence to be able to measure the airline's likely performance against the criteria set by the principles that have been supposed.

6.16.1 Financial viability

This can be assessed in the simplest possible way by comparing revenue and expenditure over a given period of time. It is comforting if revenue exceeds

expenditure; the difference is profit, before tax and any other hidden expenditures are taken into account.

The most common expression of financial performance associated with this viewpoint is the profit/loss statement. Most airlines will supply to their economic regulators (and thus make public) a monthly profit/loss statement, which may be published several months in arrears, but which can be drawn together over a 12-month period to present an annual account. These data are sometimes produced in specialist aviation press magazines and provide evidence of issues that affect the daily operation of airlines. They will show, for instance,

- seasonal variations, which might be most pronounced on ‘regional’ airlines
- public/bank holiday variations, which might coincide with religious festivals
- global influences, a downturn in economic performance, a natural or other disaster, and similar events.

Of these, seasonal and holiday effects can be predicted and there will be detailed planning to cover their occurrences. The implementation of service variations at this level of detail is closely aligned to airline operations. Global influences are ‘external’ and are the kind of events that can test the financial robustness of airline plans.

Some analysts look at the ratio of revenue to expenditure (revex ratio) to judge overall viability. A revex of 100 is when revenue and expenditure are equal, and for a revex of 110 the revenue exceeds expenditure by 10%. A 10% excess of expenditure over revenue is a revex ratio of 90. A review of most airlines accounts, as published annually by organisations such as IATA, shows that the revex of large airlines is generally around 105 to 110, with some years below 100, and a cyclical variation over several years; in some periods it has seemed to be a seven-year cycle. The average revex is about 104, suggesting that roughly 4% of revenue overall is profit. This sounds small, but on a $10 billion annual turnover this is, nevertheless, a $400 million annual profit. In perspective, it is equivalent to the revenue from a two-week period. Airlines do not always run at a profit. Winter slumps can cause an airline to be ‘in the red’ for a number of months every year and then financially buoyant over the summer, making for a decent average over the year. Airlines are loathe to see any decisions taken that will affect what they perceive as a very fragile ‘bottom line’, which is all too common in this era of passenger and movement levies, whether justified on security or environmental grounds.

Note that revex is usually measured after all expenses have been taken into account, so the profit will be after tax and shareholder dividends have

been paid, for example. The straight ‘trading profit’ can be hidden and might be substantially greater than published accounts will show.

A long-term investor, such as a leasing company that is arranging the financing of a fleet of aircraft, will want to delve much deeper and will look into the instantaneous value of the debt/equity ratio, at long-term borrowing and at the trend in such measurements of financial performance. This can mean that for substantial periods the airline, in addressing future development through route development or fleet acquisition, might choose to operate unprofitably. If they have a forecast of the way that profitability will be affected by plans and they present evidence that they are managing the process successfully, this will count towards good viability.

Airlines often sit on large amounts of cash, paid by customers in advance of flights. In most well-regulated countries these funds cannot be regarded as an asset. They are held as a bond, which might be used as security against borrowing, providing that the risk is underwritten on the insurance market. If the airline does have to cease trading, the bond should ensure there is money to pay for the recovery of stranded passengers, as without such protection they would be simply a creditor and would be queuing with service suppliers, aircraft leasing companies and banks. They are assured of some protection.

6.16.2 Regulatory compliance

Compliance has many facets, and economic regulatory compliance is already evident in the way that financial viability has been described. There is much more, however.

Safety compliance is largely an airline operation responsibility. The airline will have a licence and some of the named staff requirements and operating region limitations this will entail have been described. The named staff will have a responsibility to ensure compliance with crew flight-time limitations (FTLs), mandatory training requirements, an aircraft certificate of airworthiness and maintenance compliance, and other statutory articles. This is not so one-sided as it might seem, and in most well-run airlines the senior staff and the regulators will be well known to one another and will have times when they meet to solve issues that arise. Regulators also analyse mandatory occurrence reports (MORs), and in some countries they will be given access to databases that are run by organisations that do not have a regulatory mandate (the confidential human incident reporting procedure (CHIRP) system in the UK is an example). If they believe there is a trend that deserves debate – it might be a series of unrelated events that they construe to suggest that non-mandatory training of some staff is not proceeding at the level necessary to maintain an adequate safety standard – they are empowered to open a debate in order to look for an agreed plan of

action and to monitor progress against objectives. A good safety regulator will seek to solve issues in this manner rather than wait for serious incidents and then to invoke their most powerful mandate, of revoking the licence of an individual, a group of individuals or an organisation.

On the aircraft itself safety is the responsibility of the crew, and it is clearly the responsibility of the flight crew to fly the aircraft according to safe procedures and to handle unscheduled events with minimum effect on levels of safety. The cabin crew are there, first of all, for safety compliance. They are trained to handle emergencies, so it is no coincidence that they sit by the main doors at take-off and landing.

Security compliance is usually a national responsibility, although there will be international facets to the work too. The airline will have a responsibility to vet all passengers, goods, baggage and other articles carried as payload, which they might subcontract but nevertheless for which they will be held responsible.

Environmental compliance has been a growing feature of aviation operations, affecting airlines and airports in particular for some 40 years. The turbojet airliners of the 1960s were intrusively noisy and were so frequent at busy airports that they constituted a real noise nuisance and could be predicted to become a serious threat to health – physically and mentality. There has been respite, with turbo-fan engines – admittedly introduced because they are more efficient than turbojets – using slower moving air mass and creating diminished noise. There was a profound reduction in noise levels while aircraft size increased in the 1970s, and there has been a steady diminution of noise nuisance per operation as every new type has been introduced ever since. There are noise certification regulations that an aircraft must pass during development, and failure to meet statutory noise levels (measured under the approach, sideline and under the climb-out) can lead to certification being refused.

Noise has also become synonymous with air pollution. The larger aircraft do burn more fuel, but the fact that it is less per passenger than hitherto is no longer regarded as an adequate argument. The air quality in the wake of aircraft, measured in terms of hydrocarbon and more noxious gas emissions, is being increasingly regulated. The airlines and airports share the burden of creating operational solutions that meet local needs, as well as being compliant with regulatory accords. The room for flexibility on these issues is reducing year-on-year, and the way that environmental compliance will affect operation is so clearly grave that aircraft designers are having to reconsider the design of their airframes, the way they install and operate engines, and so on. The solution to the dilemmas faced by the industry overall will be one of the major issues debated in the future, and thus is accorded greater coverage in later chapters of this book.

6.16.3 Efficient use of resources

This is not a stand-alone topic, in that it has been alluded to in both preceding sections. The efficiency of an operation is measured crudely by some statistics. Aircraft annual utilisation is one, with most airlines nowadays trying to get several thousands of flying hours per year from each of their aircraft. Some of the pros and cons of aiming too high or two low have been discussed in this chapter, and similar attribution given to the way that safety-critical items and personnel are employed. An airline will audit the utilisation of such facilities as the maintenance hangars, flight-training simulators, specialist ramp equipment, and even the baggage bins and galley carts. A simple spot check on efficiency in an airline is to assess the number of crews per aircraft, irrespective of the annual utilisations posted. A very unreliable measure is the number of employees per aircraft, or per passenger, or even passenger-km. The problem when such wide-ranging statistics are developed is that they may mask a tendency to outsource (which makes the data look good) or to do work with in-house employees. The latter might even be outsourced for a proportion of their time (say, handling other airline's flights between the periods when they handle their own), so productivity might be higher than it appears to be.

Provided an airline takes care to utilise people as well as equipment, the efficiency aspect of the business should be in balance with the other issues that need to be considered. The human resource department should be able to assist a manager to remain aware of people's skills, ambitions and attainments. The fact that people do a good job does not mean that they should be left there. They might aspire to quite different work. Opportunities should be recognised and people guided rather than managers having to wait until appraisals throw up expressions of dissatisfaction.

The balancing of people's aspiration with organisational needs and aspirations is often the most significant contributor to efficiency in a workforce. The path is easiest with young employees, whose skill base is still maturing and whose curiosity often makes then inquisitive to move from post to post. As people get older the temptation to stream those suited to 'management' to those who are more 'hands-on' is often the most critical and poorly handled issue of all. However, in an airline, where the business might occasionally slump, but where growth is almost assured, the opportunity to build the business and people in harmony is perhaps easier than in almost any other business.

6.16.4 Effective service

In the context considered here, effective service is about the attainment of corporate goals that focus on customer satisfaction. A passenger will be

attracted back to an airline whose service has suited their needs, and while the attainment of satisfaction over all categories of passengers is desirable, it is expensive to achieve. Airlines that desire such wide success, as has been discussed above, regularly have three-class cabins to attempt that, but some airlines use just one-seat configuration and tailor demand, capacity, time and price as carefully as possible to get what they see as effective use of resources, and believe they can judge the customer service qualities accordingly.

Service quality is the leading issue in effectiveness but measuring it is an art that has yet to develop the finesse of science – arguably that will never occur. A passenger will appreciate the quality of a seat of greater width, or with extra pitch between seat rows, and they will attribute qualities to the availability of in-seat entertainment, good food and drinks service, and so on. There is a lot to be said for trying to measure what passengers like and dislike, and the latter can be the catalysts that will allow others to contribute towards solutions.

An airline that said it was finding long-haul passengers disliked seats by the lavatories on aircraft because of the disturbance caused by users, the high probability of a queue at the end of a flight and the occasional smell from chemical toilets took its views to an aircraft manufacturer. They reasoned that on the longest-haul operations the belly holds were only partially filled with baggage and little freight, and so they devised an innovative stairway into the hold from the cabin that replaced the space that would be occupied by an on-deck toilet. Below the cabin they could create a queue space and a number of washrooms. The design improved access to toilets, lessening queue length, removed the queue from nearby seats and ensured that any noxious smells were banished from the seated passengers. This is a clear example of getting a requirement expressed in the right terms (customer service led and not just efficiency in a technical sense) and getting a solution that one element of the system delivers to another element.

An issue that is making designers challenge their efficiency criteria at the current time is the 'dissatisfaction' that people express when, having become accustomed to the two-aisle configuration of a 'wide-body' type, they are thrown into a single-aisle 'narrow-body' aircraft. The addition of a second aisle, in excess of 50 cm wide, to a six-seat per row aircraft, which has an external diameter of perhaps 3.5, increases the frontal area by some 30%, which can have a considerable impact on aircraft drag, and thus every efficiency indicator. Designers will not sacrifice such efficiency for the effectiveness that the airline will say it can sell, given that the passenger will have to pay an increased ticket price to cover extra operating costs. If the increased frontal area was perhaps half this value, 15%, the fuselage could be increased by some 0.3 m. Would a 'wide-aisle' aircraft with some 80 cm between opposing seat rows appeal? If the passenger could squeeze past a

galley trolley (that is not necessarily a good criteria) it might be regarded as a good improvement. However, here is an example of the ways that commercial entities (airlines) can influence the decision-takers in the technical providers (the aircraft builders). Making the decision to go 'wide-aisle', if anyone ever does it, will be a prime example of balancing the quest for commercial reality with technical feasibility.

The previous paragraph has established that there are ways in which two of the four elements of the air transport system considered here can be linked, and it is easy to surmise that this is just one of a number of possible links. More will be established and explored, because it is firmly the case that this is where progress will be most attainable in the future, giving cooperative rather than isolationist existences. The next two chapters drive deeper into this newly emerging world of exciting and far-reaching opportunities.

7
Airports

Abstract: This chapter builds links between airports and the aircraft and airlines that they serve and the airspace providers that serve them. It starts with forecasts and requirements that determine the scale and disposition of a site. Safety-related regulation effects are described, and the functions that accompany arrivals and departures, plus formalities in the terminal, are considered. While airlines strive to be different from each other, all airports are different, so describing them in compatible terms is revealed to require careful judgements. A set of four perspectives shared with the other elements is developed to assist in integrating viewpoints.

Key words: airport masterplanning, site selection, aircraft–airport compatibility, runway, taxiway and apron and terminal configurations, capacity, demand and delay relationships.

7.1 Introduction

While airlines strive to be different from each other, all airports are different. Their setting, scale and amenities set them apart from one another, and yet most airline strategists would happily force them to conform to so much uniformity (in the terminal at least) that if they ever got their own way, they would become a component of the system that would be hard to distinguish. In this chapter explanations are offered for their inevitable operational differences and insight is presented into what makes the operational and passenger amenities so different.

Many of the world's main airports began as municipal amenities, with flying clubs and entrepreneurial airlines sharing facilities throughout, but nowadays almost all passenger-serving airports are businesses in their own right. Aerodromes that are used for public transport duties are licensed and managed to exacting standards. Such conditions are imposed with safety in mind and employ financial strategies that aim to ensure that the whole place is run as a business. An aerodrome that has regular commercial services

provided by airlines is an airport, and it is these locations, some 2000 worldwide with a regular timetabled service, that are of interest in respect of the air transport system. There are 20 000 or more additional places where aircraft can alight and take-off again, and can range from enormous military airbases to farmer's fields. They do require airspace, and in this regard their needs occasionally do conflict with those of the airport operators and users. This is a difficult issue, and the airspace needs of all aviators are addressed in the next chapter. For now the desire is to explore what there is to know about airports to an extent that will be compatible with the way that aircraft and airlines have been analysed already.

7.2 Setting up an airport

In all countries, an airport needs a licence. This will be issued by the local aviation regulatory body, whose requirements will be based upon the standards and recommended practices (SARPs) of Annex 14 to the ICAO Chicago Convention. To license an airport the licensee has to state where it is, provide physical details and in support of the latter will need to commission a geographical survey of the site and its environs. A managing team will need to be declared, and some staff, as has been seen to be the case with airlines, have to be named and deemed acceptable to the licensing authority. Essential components of a civil airport are one or more runways, associated taxiways and aprons, of sufficient size to accommodate demand, passenger and cargo-handling facilities, plus a local airspace control unit and rescue and fire-fighting services. The infrastructure, which will include lighting and radio aids, will need to be adequate to provide the service levels expected of the airport, in weather conditions down to the operating minima that the serving airlines agree with the airport operator. Additionally it might have fuelling facilities (very few airports do not offer fuel), administration buildings, and so on.

Selling a property is said to depend on 'location, location and location', and a similar phrase can express where best to locate an airport. A magnificent airport in the middle of nowhere is unlikely to be of any use to anyone. Building a massive airport beside a small township might also be reckless, although if that township is on an island and tourism is its main source of income, the airport might be the lifeline for the commercial prosperity of the township and the island overall. Usually large airports are near large cities or towns, but this is a simple rule that is applicable in only the majority of cases, not in all situations.

Most airports in the world have grown from humble roots, and are therefore often not ideally located for modern operations. They might be conveniently located, but have congested ground links and cause annoyance to nearby residents because of the noise they create. In some cases new

airports have been built on green field sites, but these are only justifiable when the traffic levels are high; in such cases the investment is often so great as to need municipal or national financial support.

7.3 Airport demand

The forecasting of demand for passenger and cargo services from an airport is not very different to that employed to analyse airline routes. The local demand will be considered first; the larger the population that can access the airport in reasonable time, the more likely it is that there will be a justification for a service to any location. An airport isochrone is shown in an earlier chapter (see Fig. 2.3). Local prosperity is an additional factor to include in such evaluations, with greater affluence in a society invariably leading to more demand for services, across business and leisure categories. Airports that are located in a convenient 'hub' location will sometimes find that 'transfer' passenger demand is considerable. Analysis of route structures has already shown that a centrally located airport in a homogeneously populated region will outperform all other airports, simply because it will be the place where airlines that are carrying passengers travelling to/from outlying locations will choose it as the place where their users change their flights. Finally, the status of a place, in terms of it being attractive to tourism, an international business centre, etc., will generate its own demand.

The needs of the many user categories that have been recognised are often profoundly different, and airports cannot afford to ignore their different needs. This is what contributes to making airports such interesting entities to create and develop, for while business users might want lounges where they can relax and even work, leisure passengers might so strenuously desire shops, bars and restaurants or cafes that they will regard an airport as a pleasant experience even if the floor space is crowded. Where an airport develops a niche as a cargo centre the requirements will be very different; in some airports the ability to operate cargo at night and passenger operations in the day is seen as a good efficiency factor. However, extra night-time flying will not go unnoticed in the neighbouring communities so the advantages come with strings attached.

7.4 Airport siting

So far reference has been made solely to the airport being conveniently located. Where there in no historic precedent, a new airport will be located in close proximity, or with easy access assured, to population, and where meteorological records show that there are suitable weather and climatic conditions. Ideally, the site should:

- allow the runway(s) to be aligned to the prevailing wind direction(s)
- be as obstacle-free as possible, especially with regard to runway centrelines
- should not be prone to low clouds – airports perched on hills are susceptible
- not be prone to fog – river basins, where radiation fog often forms, are susceptible.

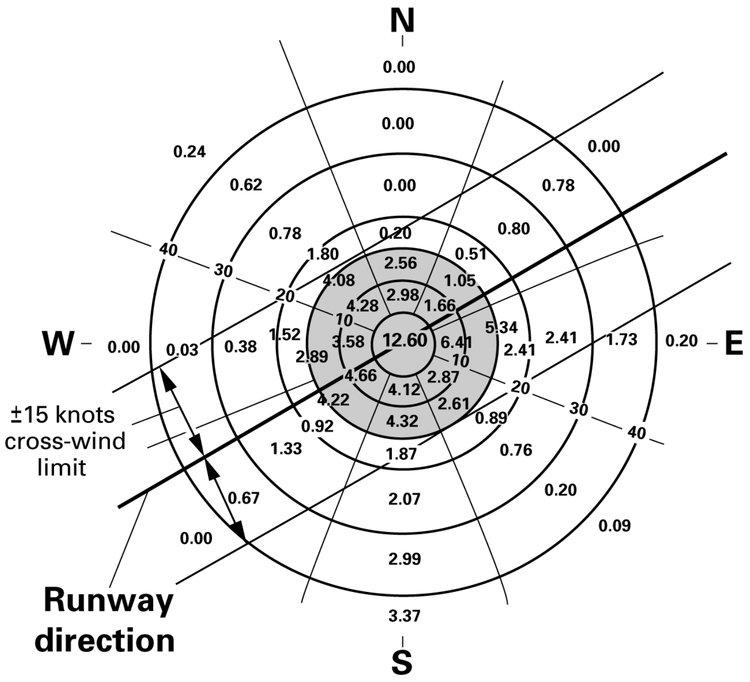
To decide which direction to align runways, it is important to remember that aircraft must take off and land into wind. It is therefore best to know if there is a prevailing wind direction and to design the airport around a runway, or runways, that will minimise the need for operations in a strong cross-wind, as such operations are less conducive to safety. Acceptable cross-wind limits are set by consideration of the extent to which a drift angle will develop. The higher an aircraft's approach speed, the more likely it is that it will have a higher cross-wind limit. Also, jet aircraft tend to have better controllability in cross-winds than propeller aircraft.

The wind rose is a graphical presentation of the frequency of time that wind is experienced in different speed and direction combinations (and the frequency is usually expressed as a percentage probability in the diagram). A wind rose is best constructed from local weather information, and a preference would be to gather observations of wind direction and speed over a long period of time (at least one year). An example wind rose is shown in Fig. 7.1.

By drawing a line in the direction of a proposed runway, as shown in Fig. 7.1, and then adding parallel lines at a distance that is equal to the maximum cross-wind limit expected to be acceptable, the summation of probability values in the enclosed area reveals the percentage usability of the runway. (The cross-wind value used will be related to criteria that aircraft operators declare in their aircraft flight manuals, which with modern jets can be around 30 knots). The wind rose thus presents an estimate of the percentage of time that a runway will be usable.

In modern designs the emphasis is on getting a single runway that will handle jet operations on an acceptable proportion of occasions. A recommendation is that the usability factor should exceed 95% of occasions. This can mean that a runway will be unusable on 18 or so days of each year, which is a considerable proportion, and it is the reason why many airports still retain a second, 'cross-wind', runway. It is usually the case that cross-wind limitations are more critical when landing than on take-off, and as landing distance requirements for aircraft are usually less than the required take-off length, the cross-wind runway can be of reduced length.

Runway numbers arise from the magnetic direction in which they are orientated; therefore 240° is runway 24. If there are parallel runways they



7.1 Wind rose.

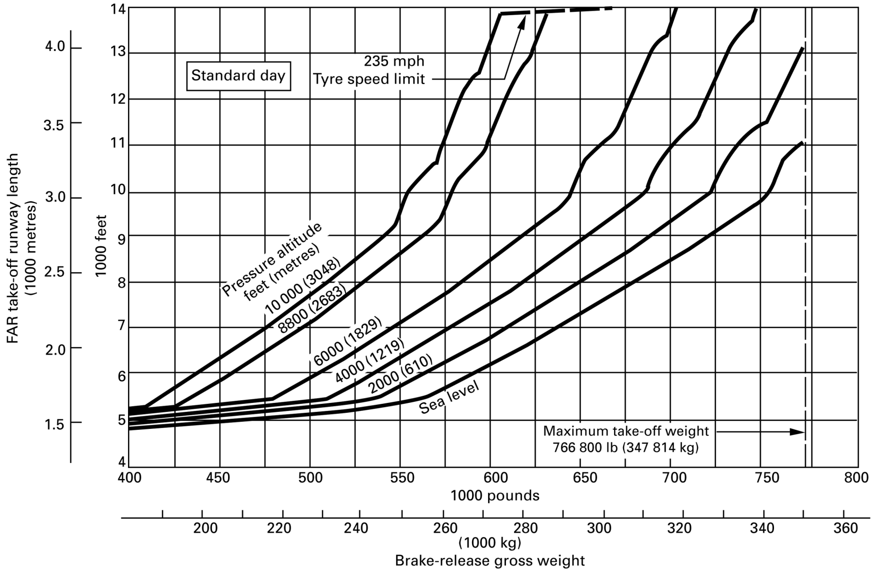
have a suffix for left (L), right (R) or centre (C); hence 27R is the right hand of a parallel set orientated 270° (in fact between 265° and 275°) magnetic. Because it can be used in either direction a runway orientated 240° will be at 60° in the opposite direction; this will be referred to as runway 06/24.

7.5 Runway characteristics

The runway is the most critical airport element, in that without it nothing else would suffice. It has numerous attributes of which paved length, obstacles and some of the physical aspects are considered here, with concentration then attached to runway capacity, or the ability of a runway to accommodate a given number of movements in a declared period of time. These attributes suffice to allow runway performance, with regard to how it interacts with other elements of the air transport system to be evaluated.

7.5.1 Runway length

Length can be such a critical requirement that direction is often compromised to accommodate an adequate length runway. The runway should be able to handle all the anticipated demand, so analysis of the



7.2 Aircraft take-off field performance.

requirements of the anticipated aircraft types and the services they will operate is an essential design task. This is not easy when an operational requirement based on a future scenario is being investigated, but since turbo-fan aircraft have become commonplace the correlation between runway length and range requirements has tended to stabilise, and even slip back a little, making shorter runway airports more competitive.

The previous notes on aircraft have shown how take-off mass is related to payload and range requirements. The chart for the Boeing 777-300 (Fig. 7.2) is a typical example of aircraft take-off performance. It shows how airport elevation is as significant as aircraft weight on the runway take-off length requirement. It must be stressed that air temperature also plays an important role, and separate charts relevant to different air temperatures need to be consulted to assess tropical locations.

The interpretation of such charts deserves special consideration when operations are close to the aircraft's limits, as the availability of what might seem mere tens of metres in declared distances can sometimes have a profound impact on the commercial value of an operation.

7.5.2 Runway declared distances

The runway paved length is not always the runway length that is used to assess operational capability. There are four specific runway length definitions, called declared distances. The definitions are as follows.

Take-off distance available

The take-off distance available (TODA) must exceed the take-off distance required (TODR) for each operation (TODR is the value considered in Fig. 7.2). The TODR is defined as: 'With all engines operating this is the distance required to accelerate to rotation speed and achieve a scheduled screen speed at a height of 35 ft (10 m) plus 15% of the total. With an engine failure at V_1 the distance is not factored by 15%'.[1]

Take-off run available

The take-off run available (TORA) must exceed the aircraft take-off run required (TORR) for each operation. The TORR is defined as: 'With all engines running this is the distance required to unstick plus one third of the airborne distance between unstick and the screen height of 35 ft (10 m) plus 15% of the total. With an engine failure at V_1 the requirement is similar but not factored by 15%.'

Accelerate–stop distance available

The accelerate–stop distance available (ASDA) must exceed the accelerate–stop distance required (ASDR) for each operation. This is defined as: 'The distance required to accelerate on all engines to V_1, at which an engine failure is assumed, and then bring the aircraft to a halt.' Some authorities permit the use of thrust reversers in establishing this distance, but then add 10% to the stopping distance. Variations in such definitions exemplify how international regulatory guidance stops short of being 100% prescriptive, but forces a common orientation in the way that safety standards are applied.

Landing distance available

The landing distance available (LDA) is usually less of a constraint than take-off. However, a wet surface, especially slush, is a serious impediment to stopping.

All licensed aerodromes will present the above four declared distances in their national aeronautical information publication (AIP). The subtle

[1] V_1 is the take-off safety speed. For the crew this is a vital defining point in the take-off process, with any event that is judged to have a bearing on the safety of an operation occurring before this speed triggering an aborted take-off. The most common quoted case is an engine failure. The evaluation of V_1 will have ensured that, beyond this speed, in the circumstances present on the day, the crew will have the ability to become airborne and to climb safely.

variations between published lengths will alert a user to the presence of obstacles that have been taken into account in the derivation of the distances, and the obstacles will be listed. Note that the TODA can exceed the runway paved length (usually by a small amount, but it can be as great as 50% in specific cases). All other declared distances will be equal to or less than the runway paved length.

Any aircraft using a runway that will need more runway length than is available to operate at its maximum take-off mass is obliged not to exceed the restricted (or regulated) take-off mass (RTOM). This is determined by entering the performance chart with the appropriate declared runway distance. (Aircrew are required to remain competent at using their aircraft flight manual graphs, but increasingly an airline will have a computer system with airport and aircraft performance databases that will perform this task for them.) Because of the 'safety factors' included in the declared distances, when operating at the maximum permissible mass from a particular runway in normal operations an aircraft still becomes airborne long before it reaches the runway end. If a crew does abort at the V_1 speed, the certification criteria should ensure that there is adequate runway length still available for the aircraft to come to a halt or to become airborne and to clear all obstacles, with one engine failed.

7.5.3 Aerodrome areas

Additionally flat and clear areas around a runway are essential, for operations at an airport. These can be within the aerodrome boundary and beyond it.

Runway strip

The runway strip is a region around a runway, which should be relatively flat and unobstructed. It protects an aircraft and its occupants in the case of running off the runway, and eliminates obstacles that might be hazards if the aircraft deviated from the runway centreline during a go-around. Small installations that are deemed essential to safe aircraft operations are allowed within the strip (e.g. lights and signs), but they have to be frangible.

Runway end safety areas

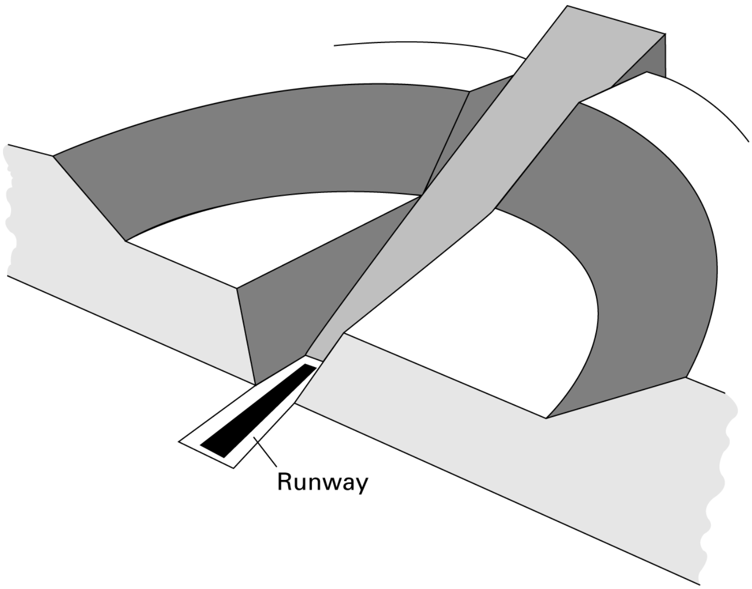
Runway end safety areas (RESAs) are regions beyond the runway strip in which it is assumed an overrunning aircraft will come to rest. In recent years the desirable length has been increased from 90 to 240 m.

7.5.4 Obstacle safeguarding

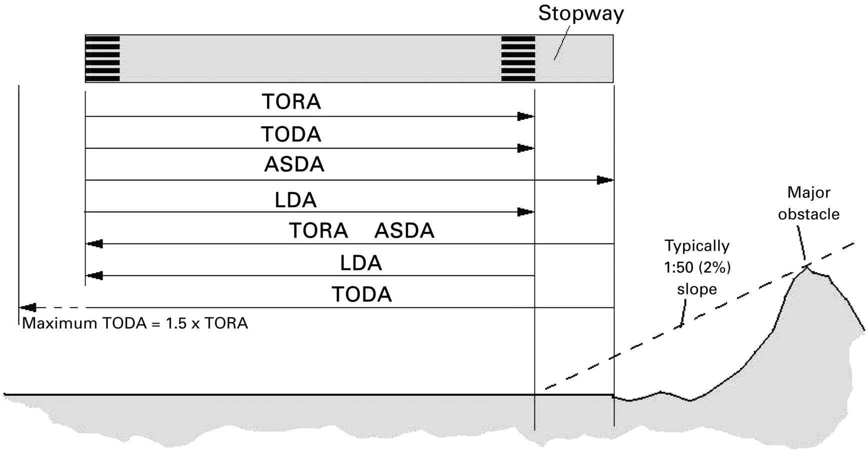
Beyond the airport boundary, obstacles can be relevant at up to 20 km from an airport and their impact on airport operations can be considerable. The regulations here are fluid, however, and where there are significant and unmovable obstacles procedures can be developed that will require due diligence and be acceptable to regulators. The most obvious example in recent years was the Hong Kong Kai Tak airport, where aircraft flew an approach along an offset ILS and turned in the final stages of the approach while relatively low over a heavily built-up area of the city. This was acceptable while demand could be accommodated, and in the late 1990s a new airport was introduced about 20 km away that has allowed less hazardous procedures to be used.

Figure 7.3 shows the obstacle limitation surfaces (OLSs) that are defined for an airport runway (exaggerated, for in reality the gradients are very shallow). The application of these criteria is sometimes referred to as ‘aerodrome safeguarding’. There is a degree of ‘common wisdom’ in how these surfaces are described, but there are collision-risk models (CRMs) that can be used to substantiate risk. This kind of analytical process is used to justify procedures that pertain to airports in difficult locations.

If there are obstacles beneath an approach, the extent to which the most significant example penetrates the obstacle surface will determine to what extent the surfaces are ‘displaced’ (towards the runway). An 8 m penetration



7.3 Airport obstacle planes.



7.4 Runway declared distances, with an obstacle (the TODA to the left might extend beyond the paved length – see notes).

of a 2.5% slope will lead to an $8 \times 100/2.5 = 320$ m displaced threshold. This will create a region of the paved runway that is unusable for declared landing distance. However, it will still be usable when aircraft depart in the same direction. The way this kind of consideration affects declared distances is shown diagrammatically in Fig. 7.4.

7.6 Runway capacity

The likely number of arrival and departure movements per hour that a runway can accommodate is crucial to determining how busy an airport can be, either in its peak or, if it is a very capacity-constrained airport, continuously. There are several very precisely defined capacity definitions. Two are of interest in this text, which will be adequate to allow assessment of an airport's traffic capability.

Ultimate capacity is the maximum number of movements per hour that a runway can achieve. It is usually a theoretically determined figure, developed from a mathematical process that considers the mix of traffic, usually divided into four categories:

Heavy	all airliners that require 'wake-vortex' separation
Medium	all jet airliners and business jets, and some large propeller types
Light	all propeller aircraft, excluding single-engine propeller types
Small	single engine, typical up to six-seat, general-aviation types

A representative runway occupancy time (ROT) for each category is determined and the separation standards used at the airport are evaluated. Although the evaluation has many undeterminable elements and statistical techniques are used, ultimate capacity may be expressed as a precise value, for example 57.56 movements per hour. It may occasionally be exceeded for short periods, but the implication is that operations are running favourably to achieve this value, and thus it is never likely to be exceeded, or even sustained, in service.

Sustainable capacity is the movement rate deduced from the ultimate capacity, but usually expressed as an integer value. It has been reduced by a proportion that equates to a predetermined delay and can thus be regarded as sustainable in normal operations. The sustainable capacity of a runway with an ultimate capacity of 57.56 movements per hour might be around 50–54 movements per hour.

7.6.1 Evaluating runway capacity

The runway occupancy time (ROT) of an arriving aircraft is determined for each category of aircraft type by combining the physical characteristics of the runway – specifically length and position/configuration of entry and exit taxiways – with aircraft performance data. The aircraft categories roughly classify aircraft by approach speed. The 'heavy' category aircraft are segregated because they create sufficient wake turbulence to have a more severe approach spacing criterion applied to them.

The landing distance required (LDR) for each aircraft type is the runway length required measured from the threshold to the point where the aircraft will stop. The actual landing distances measured in normal operations always show considerable differences to what is published, as the actual distribution is influenced by taxiway positions, the relative location of the airport terminal, and – where it has a psychological impact on the aircrew – the visible terrain. It is necessary to observe or postulate the distribution of use of taxiways by each category, and then with an associated ROT value to deduce an average ROT value for the whole traffic sample. A sample in Table 7.1 presents some observed ROT values between 38.5 and 72.3 seconds and an average ROT for the traffic category of 48.056 seconds.

If the data in Table 7.2 referred to 'medium' aircraft and the 'heavy' aircraft average ROT was 61.312 seconds and the 'small' (turboprop) category ROT was 32.831 seconds, then it is possible to calculate an ultimate capacity for the runway, provided the proportions of operations by aircraft in each category are known. For an example assume that the proportions in heavy, medium and small categories are 15, 56 and 29% respectively; an average ROT for the arrivals in the complete traffic sample is shown in Table 7.2.

Table 7.1 Arrival runway occupancy times in detail

	Taxiway						
	G	F	E	D	C	B	A
U = usage (%)	0	3	48	47	2	0	0
R = ROT (s)	0	72.3	51.4	43.5	38.5	0	0
$(U/100 \times R)$	0	2.169	24.672	20.445	0.77	0	0

$\sum = 2.169 + 24.672 + 20.445 + 0.77 = 48.056$

Table 7.2 Average arrival ROT

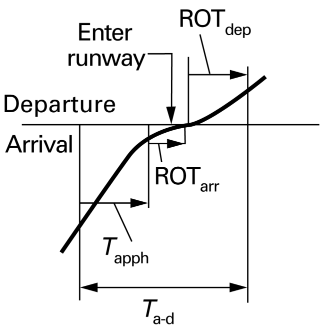
Category	ROT	Sample	Contribution
Heavy	61.312	0.15	9.1968
Medium	48.056	0.56	26.9674
Small	32.831	0.29	9.5210

$\sum$ = 45.6852 seconds

The ROT is heavily biased towards the value used for the medium category, which indicates that it is by far the most dominant category. Provided the traffic mix is so distributed, the extent to which the average ROT will change will be relatively small.

So far only the ROT of arriving aircraft has been considered. The evaluation of departing aircraft ROT values requires knowledge of access points, an allowance for line-up and the roll-time from brakes-release to airborne. It is usual to regard the runway as 'occupied' until the aircraft has exceeded a height of 10 m (35 ft) or so.

Where arrival and departure movements are equal, they can be assumed to be conducted alternatively. The sequence of timings (and example timings that are indicative only) is shown in Fig. 7.5. The timeline sequences and periods are defined and applied thus:



7.5 Timeline of the arrival–departure sequence.

- T_{apph} is the time taken by arriving aircraft to fly from the point where they are given clearance to land to crossing the runway threshold (assume 60 seconds).
- ROT_{app} is the runway occupancy time evaluated (use 45.69 seconds from the example).
- The departing aircraft is assumed to enter the runway after the arrival has passed its entry point (usually, but not always, the threshold).
- Clearance to take-off follows soon after the arrival has vacated the runway (assume 5 seconds).
- ROT_{dep} is the time taken for the aircraft to be airborne and to reach the point where the next arrival aircraft can be issued with a clearance to land (assume 36 seconds).

The above sequence, if valid for the runway being assessed, takes $60 + 45.69 + 5 + 36 = 146.69$ seconds. In one hour $3600/146.69 = 24.54$ combined arrival/departure movements can be accommodated, which is equivalent to $24.54 \times 2 = 49.08$ movements per hour.

There are several operational issues that need to be studied before the above sequence is accepted. These include assessment of:

- whether departing aircraft need to enter and backtrack the runway (and whether this time will be absorbed in the time taken by the arrival to pass its point of entry and leave the runway)
- whether T_{apph} will be larger when an arrival is following a previous arrival that was a 'heavy' aircraft
- whether an average ROT_{dep} is acceptable, just as ROT_{arr} was averaged.

These are typical issues and illustrate why simply looking at an indicative ultimate capacity figure in a reference is often not adequate to determine the capacity of an actual runway.

Figure 7.6 presents some broad assessments of runway capacity values that can be assumed to apply to a number of commonly encountered airport configurations.

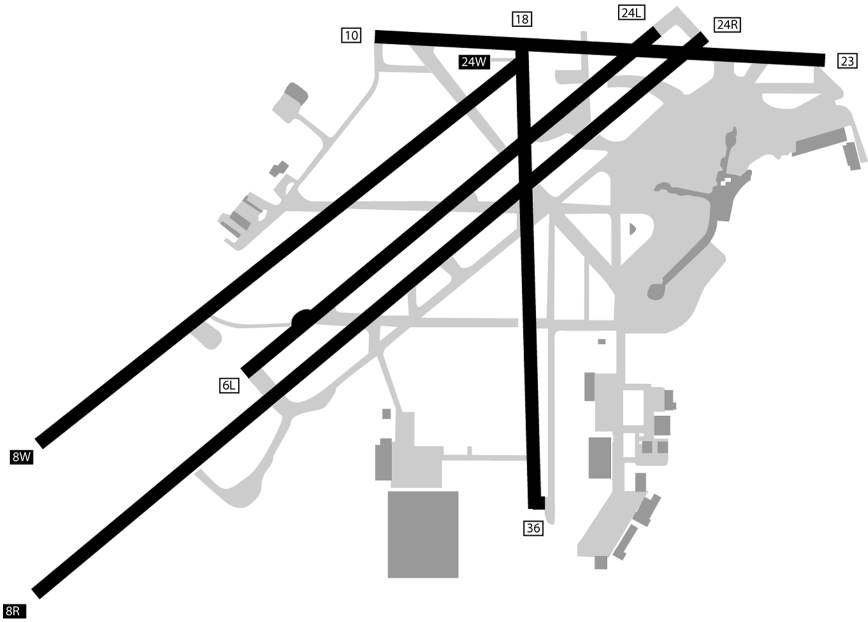
In a complete evaluation, not only would local operational issues be considered but the combinations of consecutive arrival–arrival, departure–departure and departure–arrival operations be evaluated and the probabilities of each occurring be used to factor their contributions to the whole runway operation. Large airport capacity evaluations must also take into account the interaction of runways, as six-runway airports are not uncommon at busy hubs in North America. An example airport layout (Cleveland, USA) is shown in Fig. 7.7. The associated runway capacity chart, which has become known as a runway 'benchmark' diagram since the FAA began to publish annual 'benchmark' assessments of runways in the USA, presents the arrival and departure capacity in the form illustrated by

	Air transport operations – all-weather	
	Movements/h	Movements/year
Single runway	50–59	195 000–240 000
Close-parallel runways	56–60	260 000–355 000
Independent parallel runways	99–119	305 000–370 000
Widely spaced close-parallel runway pairs	111–120	550 000–715 000

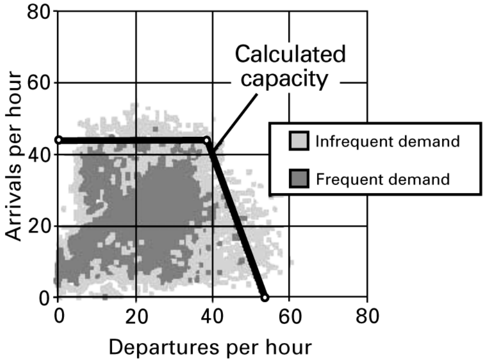
7.6 Airport configuration and capacity (Source: FAA capacity handbook).

Fig. 7.8. The points superimposed on the capacity 'envelope' on the chart are the airport hourly demand statistics. Clearly, to cope with demand in all circumstances the demand points should be within the capacity envelope.

The evaluation of data for a particular airport requires analysis of runway operations under different air service rules (essentially visual and instrument



7.7 Runway configuration for Cleveland, Ohio, USA (Source: FAA benchmarking report 2005).



7.8 Example benchmark capacity chart for Cleveland (Source: FAA benchmarking report 2005).

rules, which will be discussed in the next chapter). The airport demand might also change, in that some operations might diminish or cease (either grounded or diverted) when instrument flying conditions fall below the minima imposed by operations.

A few words of warning about the validity of such evaluations are essential, given the prominence the data from such evaluations exert on issues that are considered in later parts of the book. The above evaluations assume proportions of movements in each category, but most runway capacity assessments concern the future use of a runway and require estimation of the proportions of aircraft in each category. Because a runway may be configured for operations several decades in the future, at the 'design' stage the information available from airlines, whose horizons are often months and a few years at most, is rarely as reliable as a planner would like.

In these evaluations, it has been assumed that there is no airspace constraint applying to the runway arrival or departure streams, and the runway has been assumed to be unaffected by an adjacent or intersecting runway. The way that runways interact and operations are affected by terminal position influence ATC procedures, so the refinement of capacity is addressed further in the next chapter.

The material presented here has indicated how an initial capacity might be conducted to justify a configuration choice at the initial airport planning stage.

7.6.2 Sustainable runway capacity

The derivation of a sustainable capacity is often rigorously defined, but using different criteria, depending on the organisation conducting the study. While the variation in answers is small these differences are hotly debated,

given that an assumed extra movement per hour can amount to perhaps 16 extra movements per day on a runway or some 5000 movements per year. With income at around £10–20 per arriving passenger in the UK (2007), at an airport with an average of 120 passengers per movement this can affect the presumed annual revenue by as much as £6 million per annum. In many cases an airport will declare a sustainable capacity that is 90% of the ultimate, and leave it simply at that. The reasoning is that this results in a traffic load that experience shows ATC can handle without excessive delays. In fact, the relationship between capacity and delay is inherently complex, and is an issue that will be returned to within a more detailed explanation of ATC issues in the next chapter.

An ultimate capacity of 49.08 movements per hour, using the simple criterion already quoted, would translate into an assumed 44 movements per hour per runway. Throughout the USA common runway capacity definitions have been developed by the FAA and researchers, and a similar process is being pursued in Europe, under the auspices of a project – Single European Skies (SES) – that is EU approved and administered by Eurocontrol. This seems unlikely to adopt US airport and airspace evaluation definitions and processes, given that European operations can be argued to be different to those in the USA, but the need for a consensual set of parameters and evaluation procedures is by now a pressing requirement for airport and airspace planning organisations.

7.7 Runway pavement strength

The physical properties of runways are worthy of considerable debate and yet are accorded only a brief overview here. Pavement strength is critical to operations and is expressed by a pavement classification number (PCN). This is determined by design and is dependent on materials and subgrade depths and quality. The PCN value of a runway will tend to reduce with age (it can actually increase in some circumstances, for example curing concrete), but, in general, provided the PCN value equals or exceeds the aircraft declared ACN value, the operation is permissible. The aircraft classification number (ACN) is determined by the manufacturer at the design stage and is dependent on such issues as MTOW, undercarriage overall geometry, the spacing of individual wheels on a multi-wheel landing gear unit and actual tyre pressures. In general, the larger the aircraft, the larger the ACN number, but there are surprises. Professional advice is essential for operators who are conducting marginal operations, in that ACN can exceed PCN by as much as two-fold and the movement (if it is rare) will be deemed acceptable by the regulatory authority. The runway condition needs to have been regularly monitored and the airport operator

has to agree to the operation. They will need, for example, to consult their insurance conditions as well as consider technical issues.

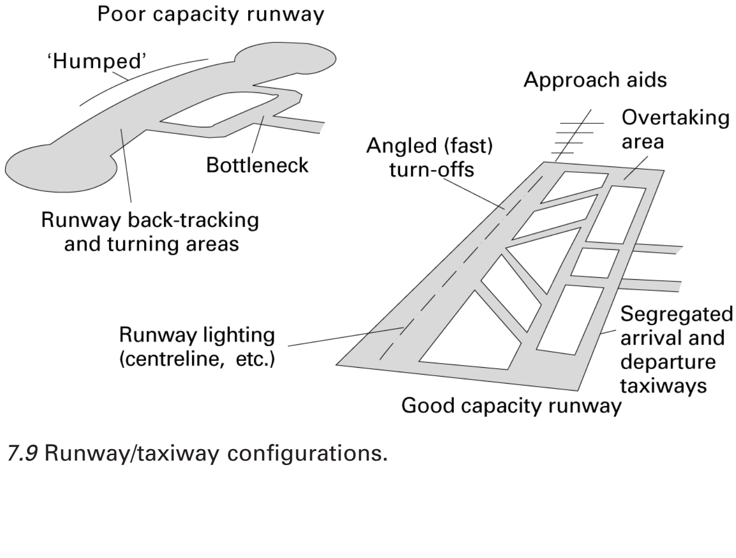
7.8 The manoeuvring area

Beyond the runway and extending up to the airport terminal(s) is the manoeuvring area. Official definitions exclude the apron (or ramp), as different operational conditions can apply on the apron, but the common point that is of interest here is that their design must ensure that maximum efficiency is drawn from these facilities.

The apron and the taxiway/runway configurations are critical to achieving a sustainable high movement rate on an airport. Ideally there will be more than one exit from an apron to allow access/egress in the event of a taxiway becoming blocked (by an accident or through the need to perform maintenance). It is also desirable, if a high movement rate is expected, that the taxiway system allows departing aircraft to manoeuvre to the runway entry point without needing to enter and 'backtrack' on the runway.

A taxiway parallel to the runway and running its full length is a minimum requirement for a busy airport (one whose movement rate will regularly equal the capacity of the airport). In ideal circumstances there will be two parallel taxiways and overtaking areas, where the order in a departing aircraft queue can be changed. These conditions can be assessed from an airport plan or photograph, and examples are shown in simple terms in Fig. 7.9.

The taxiways must be strong enough, wide enough and sufficiently spaced relative to other manoeuvring regions to ensure that aircraft wheel track and turning circle needs are met and that the risk of aircraft clashing is



7.9 Runway/taxiway configurations.

minimised. On large airports it is usual to ensure that the minimum taxiway width is 23 metres and that there is a minimum separation of 190 metres between the runway and parallel taxiways. At least one-half of this distance should be available between adjacent sections of parallel taxiways.

The taxiway configuration is vital to attaining a sustainable operational capacity. The leading criteria on which taxiway configurations can be assessed include:

- *Runway access/egress*. The more points at which aircraft can enter or depart the runway, the more likely it is that the runway occupancy time (ROT) of arriving aircraft will be minimised. Likewise, departing aircraft can have their ROT minimised by having taxiways access at the ends of the runway (already apparent in the runway capacity assessment).
- *Turn-off geometry*. Angled turn-offs, sometimes called rapid-exit taxiways (RETs), allow arriving aircraft to turn off without having to halt and conduct a 90° turn, which can take a great deal of time.
- *Parallel taxiway*. A taxiway, appropriately spaced, that extends the full length of a runway can be the most suitable way to allow access/egress, and is probably essential when an hourly movement rate in excess of about 20 aircraft is proposed. When a very high movement rate is expected, it can be valuable to have two parallel taxiways.

7.8.1 Airfield lighting

Runways have runway and approach lights. The approach lights are set along the extended centreline, with cross-bars that decrease in width (the edges aligned to meet at a point 300 m within the approved runway length) as the runway is approached. Lights are white and relatively directional. They are mounted above the runway surface level, but if they are within the runway strip and RESA they must be attached to frangible posts that will shear and not impede an object, such as an undershooting or over-running aircraft.

The most complex installations will extend 900 m from the threshold and have cross-bars at 150 m intervals and side-bars (parallel to the extended centreline lights: red and sometimes called barrettes) at 30 m intervals from 270 m to the threshold. The threshold will be marked by a closely spaced row of green lights (shining up the approach) and red lights will show down the runway.

The runway lighting will comprise white lights along the runway edge, spaced at 60 m maximum, and for low-visibility applications there will be 15 m spaced centreline lights. The side-bars (barrettes) extend from the threshold to 300 m into the paved area, again at 30 m intervals, but using

white lights. Where a displaced threshold is used, the displaced threshold will be the datum for the lighting system.

The most common approach guidance lighting is the PAPI (precision approach path indicator). All lighting is so crucial for all-weather operations that they must be supported by a dual-redundant electrical power supply, so that no one power discontinuity will cause loss of visual reference. This is similar to the safety requirement applied to radio communications and navaids, but the power requirement and instantaneous 'switchover' time requirements are particularly onerous. There has been widespread acceptance of solid-state lighting (usually light-emitting diode (LED) technology) as these lights are more durable and use less power than filament lamps.

Taxiways usually have blue lights at each edge and green centreline lights. Where a taxiway can lead to a runway, red stop-bars are placed across the taxiway. On large airports (notably London Heathrow) taxiways are divided into blocks, and the ground controller will direct a user along a path, terminating at a red stop-bar.

Aprons are usually well lit by floodlights, and those stands that are adjacent to terminals, especially if they have jetties to load/off-load passengers, will often have an optical guidance system. At small airports a marshal will direct aircraft to a stand using hand-held wands. These are illuminated at night. Stands have markings relevant to various aircraft types so that the crew align the doors with jetty access zones. Aircraft doors are assumed to be on the left-hand (port) side of the fuselage, with servicing and freight hold doors on the other side.

7.9 Aprons

The apron is the holding area where aircraft are parked for disembarking and embarking passengers. It has to provide sufficient parking to cope with peak demand. On small airports this is achieved by a small hard-standing adjacent to the terminal. If the airport has 'self-manoeuvring' stands, aircraft will park at an angle (skewed or even parallel to the terminal frontage), and the airport is saved the chore of providing tractors to conduct 'push-back' manoeuvres. However, due to jet-blast hazards and as aircraft size increases, and especially in countries with inclement weather, terminal-side retractable 'jetties' are preferred, aircraft are parked 'nose-in' and push-backs are essential. An advantage is that stands can be slightly closer together, but as terminal frontage is usually limited, the extra frontage that is needed is generated by having terminal piers, or satellites. In such cases the clearances between stands is an essential consideration affecting apron size, and if a 'cul-de-sac' is created, the ground movement problems can be sizeable. Remote stands, where passengers disembark and embark from

buses, can be a compromise when traffic levels achieve sudden peaks. Because aprons are concrete hard-standings, they are often easily extended, and therefore do not constitute significant capacity constraints, but if apron expansion is conducted piecemeal, without consideration of the long-term impact on overall airport performance, the effect on service quality issues can be appreciable. If passengers have to wait for buses, walk longer distances, be held up waiting for baggage to appear at reclaim, and so on, the most economical development of an apron, while it might best suit what is available for the income generated by the handling fees that an airline is willing to pay, is a strategy that might be at odds with the service quality remits of customers.

A key consideration determining total stand capacity is the accommodation of based aircraft. If these are passenger service aircraft it may be necessary to assume that the whole local fleet will be parked overnight. Some additional capacity must also be made available for visiting aircraft. This requirement can lead to exceptional extra capacity allowance.

Throughout the day the number of stands needed to accommodate daily operations is related to the time required to complete an aircraft turnaround. In low-cost operations the occupancy can be short (25 minutes is routinely scheduled), but this can be extended by early arrival, weather and delays. Routine practice in stand allocation work is to allocate a buffer time of 15 minutes minimum between successive movements on a particular stand. This suggests, optimistically, that up to 1.5 turnarounds per hour will be accommodated on each apron stand devoted to low-cost operations.

Routinely, intercontinental flights will occupy a stand for much longer. A turnaround in excess of 1.5 hours is not untypical with a buffer time of 15 minutes again. Some services will stay even longer if they are operating a 24-hour rotating schedule. If the aircraft is not to block useful space it is pertinent to move it, after unloading, to a remote stand, and then to return it to a stand prior to servicing and passenger boarding.

7.10 Passenger terminals

Passenger terminals are the most significant facilities on civil airports. They are tailored to specific passenger's functions, such as arriving, departing or transferring between flights.

The functions that a typical departing passenger must pass through are check-in, security, passport check, departure lounge and gate lounge, while arriving passengers typically use passport control, baggage reclaim, customs control and then the arrivals hall, where they join their 'meeters and greeters'. Domestic passengers are saved the need to complete passport and customs checks. Transfer passengers – not what the airport will plan for, but the preceding chapters have shown they are a substantial proportion of all

passengers at some airports (and almost non-existent at others) – have to pass through the appropriate arrival formalities (which will include passport control if they have arrived on an international flight) and proceed to the departure lounge, thus joining the departure process. In some cases they may also be required to conduct a security check, and if their baggage has to be checked as well, the process can be almost the same as a full departure; in general, however, they do not need to check in. Transit passengers are often 'transfer' in terms of the access they need, but the implication is that they arrive and depart on the same aircraft, so baggage is not unloaded. This might be for a 'tech-stop' or refuelling. Transit passengers are not usually numerous, especially now that longer-range aircraft are in use. Transfer passengers, as the routeing considerations have shown, are plentiful and can even swamp the arrival and departure (terminal) passenger numbers at 'hub' airports.

Airlines, as has been shown, appreciate that there are preferred times for flights, which means that most airports experience very appreciable changes in demand throughout a day. In setting up an initial assessment of the hourly capacity that will suffice to gauge the design of passenger-handling facilities, it is important to develop an understanding of the proportions of operations at an airport in various passenger categories – business, leisure, terminal, hub-transfer, and so on.

Generally, the smaller the airport, the more significant, in proportional terms, is the daily peak. Thus, chasing efficiency (in terms of the physical resources and also manpower) is considerably more difficult in airports with small passenger numbers than in large airports. The smaller an airport, in terms of annual passenger throughput, almost inevitably the less efficiently it can use its facilities.

7.10.1 Terminal sizing

As a general rule-of-thumb, a terminal should have about 25 m^2 per peak hour passenger. Although not always applicable, the US FAA, as long ago as the 1960s, devised a formula-based approach to identifying the number of people in the terminal in the peak hour, called the terminal peak hour passengers (TPHP), that could be used to set an hourly throughput design target. The relationship between the TPHP and annual passenger predictions is shown in Table 7.3. This rule-of-thumb can provide a simple assessment of terminal area (see Table 7.4).

These are indicative data, and terminal designs straddle the rough areas shown, often by large margins. There is no easy way of incorporating non-passenger-handling functions, such as airline and airport offices. An airport designed specifically for low-cost operations in Europe, for example, might provide only 12.5 m^2 per peak hour passenger, believing that dwell time in

Table 7.3 FAA TPHP and passenger movement relationship

Total annual passengers	TPHP as a percentage of annual flow
30 million and over	0.035
20 000 000–29 999 999	0.04
10 000 000–19 999 999	0.045
1 000 000–9 999 999	0.050
500 000–999 999	0.080
100 000–499 999	0.130
Under 100 000	0.200

Table 7.4 Simple assessment of the terminal area for a range of airports

Annual throughput	TPHP	Terminal area (m^2)
100 000	200	5 000
500 000	400	10 000
1 million	500	12 500
5 million	2 250	56 250
10 million	4 500	112 500
30 million	10 500	262 500

the terminal will be low and that as delays do occur and passengers are stranded, they will have to accept the reduced service quality that comes with inconvenience. The data do show that while larger airports have larger terminals, the scope for difference at any airport is enormous.

A widely used assessment process is the so-called IATA level of service (LOS) criteria. This allocates space to major functions, but instead of setting a definitive figure for area, acknowledges that area and service quality are transferable. The IATA level of service (LOS) descriptions are

LOS	Description
A	Excellent – free flow
B	High – few delays
C	Good – stable flows, acceptable delays
D	Adequate – flow can be unstable, delays still acceptable, but becoming frequent
E	Inadequate – unstable flows, unacceptable delays
F	Unacceptable – system breakdown, unacceptable delays

The relationship with space in various functions is shown in Table 7.5.

The value of the IATA approach is that variations on the rule-of-thumb sizing are given more association with efficient usage. Thus, an airport owner who is treading carefully between being economical and yet not

Table 7.5 IATA LOS criteria

	LOS description (m^2/occupant)					
	A	B	C	D	E	F
Check-in / departure concourse	1.8	1.6	1.4	1.2	1.0	No
Wait/circulate (e.g. departure lounge)	2.7	2.3	1.9	1.5	1.0	criteria
Holding areas (e.g. departure gates)	1.4	1.2	1.0	0.8	0.6	are
Baggage claim (excluding devices)	2.0	1.8	1.6	1.4	1.2	set

IATA LOS C or better is the design level adopted for most terminal projects.

wanting to sacrifice efficiency has a first-order assessment tool with which to associate efficiency and effectiveness.

The evaluation of actual terminal function service rates is often verified by using a computer-based simulation model. These are relatively expensive software tools in which the following data are entered:

- the daily traffic sample (aircraft types and passengers and time of arrival/departure)
- a drawing of the building and internal fixtures (as detailed as possible)
- service quality criteria (maximum acceptable queue size, wait time, etc.).

The model runs a representative traffic sample through the system, moving entities (a passenger or a bag) throughout the modelled building, and creates 'reports' on movement data or produces a scale-dimensional view of the building, on which passenger movements are presented. This can be linked to gate assignments, and is therefore linked to airside operations and airspace modelling as well as the landside access details; kerbs, car parks, even people movers and railways, can be modelled. Modelling tools take a long time to set up and their results deserve careful deliberation, given that they are statistically based and the quality of input data, especially for long-term scenarios, is often debatable. Smaller airports often feel at a disadvantage to larger airports, as the cost of terminal simulations is less easily justifiable, given that it becomes a larger proportion overall of the total design budget.

7.10.2 Terminal configuration

Aprons surround a terminal, so getting access to the stands where aircraft park is a major factor in defining overall airport configuration. Airliner-compatible stands can account for 45 to 80 metres of frontage. Consider a 30 million per year airport that has a 250 000 m^2 terminal building. It may handle passengers and baggage on three floors and will thus have some 80 000 m^2 per floor. If the building is 120 m deep the frontage will be about

650 m, which will allow direct access to between 8 and 15 stands, depending on aircraft size. With a peak hour throughput of some 10 000 passengers, if the average load is 100 people, there will be 100 movements per hour (and assume for now it is 50 arrivals and 50 departures). This number of movements cannot be accommodated on the few stands that will be directly next to the terminal frontage.

Among solutions, the 'pier' is a popular choice, but if it is too narrow it becomes a boring corridor. Furthermore, the walking distance from a terminal to the sixth stand on a pier can be 270–480 m. Several small piers can serve a more compact space, but this creates cul-de-sac aprons, and aircraft manoeuvring delays can affect surface movement capacity greatly. The costlier, but more flexible, solution is a 'satellite'. This has to be accessed through a walkway/tunnel, often with a moving walkway) or using a railway-based system (which is usually unmanned to save on operating cost). Initially architects preferred circular satellites, but as aircraft spans have increased these have become congested. They are difficult to modify so the most popular concept now is 'linear' satellites, which can be orientated perpendicular or parallel to the terminal facade. A 30 million passenger airport will have in the order of 80 stands and would probably use the frontage with small piers and two linear satellites. This would have perhaps 30 stands per location, and the designer would try to organise the terminal and apron so that the point between locations that 50% of passengers might use will be at a distance of less than 1 kilometre.

Extended walking distances conflict with the service requirement of a passenger using a 'hub', and the only solution is for airport and airlines to work closely with one another to reconcile these issues. The traditional solution is to group stands for a regular-user airline, so that their transferring passengers will find aircraft almost adjacent. The stands can become user-designated, and while the airlines will enjoy the opportunity to 'brand' them with colour schemes (if they are allowed to – and why not 'at a cost'?), they will have occupancy of space at some periods that might be useful to accommodate other airport users. The ability to find a reconcilable solution among so many airlines is often a management task fraught with difficulties.

Once 'shape' (determining points of entry and exit on a drawing for arrivals and departures) has been scaled, the physical juxta-positioning within the envelope of the building of passenger and baggage facilities is an architectural challenge. At small airports, a single-floor terminal that is expandable by tagging extensions on each end is often preferred. As the airport develops this can lead to long passenger through-paths, and keeping passenger and baggage paths apart is often a physical challenge. At large airports the architect will often specify two or three levels, with baggage handling (and air-conditioning and service deliveries) on the ground level

and departures and arrivals segregated in the first and second floors. This is a popular configuration, although it requires complex landside development. Because arrivals need less space than departures some designers have baggage handling and arrivals on one floor – usually the ground – and departures on another floor, usually above so that baggage collected at check-in is delivered to the sorting area down chutes or sloping belts.

Arrivals need least space because they are not held in the terminal. A good airport design will allow an incoming passenger to slip through without any hesitation. In the case of a passenger arriving on a domestic flight and carrying their only luggage this is very often the case.

Most passengers have to stop briefly in the baggage reclaim area and collect their hold bags. The smallest airports often have little more than a table or a sloping shelf, but in larger airports the baggage 'carousel' is now a common feature. This is a segmented flat surface which is designed to slide along and even around corners. The baggage is loaded on to the belt either directly, perhaps at a location where it protrudes from the terminal, or on a belt that feeds the carousel from within the baggage handling area. A large belt will accommodate the baggage from several flights, and to guide passengers to the correct belt it will display a sign with the flight number and the place name from where the baggage has arrived. The display is one of numerous units that are scattered around a modern terminal. They are almost all liquid-crystal or plasma displays, and the computer-based systems that digest arriving and departing aircraft information will select the information to show in different places. This is tip of an information technology iceberg, and the visible element is called the flight information display system (FIDS). There will be databases of planned and actual movement information that will be analyses to obtain delay statistics, to assess parking and passenger handing charges, and so on. There is often a port on this system that feeds directly to national TV and internet links so that data can be accessed and read directly at home.

International arrivals invariably have to pass through a passport control or immigration process, and this can lead to huge queues and delays at very busy international airports. Within a region such as Europe, most EU passport holders are able to slip quickly through such formalities.

Once reconciled with their baggage, passengers pass into customs, where they are usually trusted to declare goods they are importing or allowed to walk through if they do not carry any declarable imports. In some countries this can be a bottleneck again, some national authorities demanding, for example, to X-ray all incoming baggage and confiscating what they classify as contraband.

Departure flows are easier to visualise, requiring simply check-in, a security check and then passage through the departure lounge and gate areas. Nevertheless, the check-in area is often difficult to configure. The area

around check-in desks has to be large enough to accommodate queues, and there is the problem often of finding a route from the desk to the security check without first stumbling through the remaining queues. There was a time when all airports had sections of their departure hall dedicated to user airlines, so that each company had a few desks on which they displayed their emblems or logos. This is wasteful when an airline is only occasionally using the desks. When technology permitted they were forced to use a computer-based check-in desk that would change its displays and function to suit a number of airlines. This is a common-user terminal equipment (CUTE) desk, and brought better utilisation of facilities and floor space to many airports. Later, the common-user self-service (CUSS) unit appeared; this is a unit at which the passenger presents their ticket or enters booking details personally and allows them to 'self-check' their flight. There are two schools of thought on this system. In one case the CUSS unit is free-standing, and after validating their ticket and seat the passenger has to proceed to a conventional check-in desk where they 'drop off' their baggage. A member of airline staff or an agent has to print and attach the appropriate baggage tag; if there is a security requirement for questions to be asked, the opportunity is there. This dual-desk process does not use space as efficiently as a system where the CUSS unit is integrated into the check-in counter. A passenger with only hand baggage can opt to use a free-standing counter, while one with baggage to check in can use the integrated desk, where the unit will weigh the bag and print the luggage tag as they receive their self-service ticket. The airline representative can again intervene, if necessary, such as when baggage is over a weight limit.

Most airports desire a spacious departure concourse with high ceilings and lots of natural light, but mixing these desires with the intricacies of passenger flows and baggage flows can often be an expensive luxury. Even then, the design has to be easily expandable, and the reconciliation of requirement upon requirement is a very difficult task.

The security check was not an issue when air transport was a mode of transport used by only a small proportion of the population, but nowadays, with threats to take explosives, firearms or other harmful devices on aircraft prevalent in many communities, the security process has become a necessity, and it seems is never likely to be absent from terminals in the future. If there are 100 check-in desks at a large airport, each capable of processing 36 passengers per hour, then 3600 passengers per hour – an average of 60 per minute - have to be checked in at the security gates. It is usual to look towards handling 4–6 passengers per minute per gate, which means 10–15 security gates. To proceed through a security channel is not always a 10–15 second process, however. It can take 2 to 2.5 minutes to remove outdoor clothes (and perhaps shoes) and metal objects, to load them into trays and to pass them through an X-ray machine. Then the individual passes through

an archway metal detector (AMD) and may be subject to a body search. They have to retrieve their hand baggage and clothing items and re-dress; thus at any instant in time there can be seven passengers in a security channel. This means that a similar number of security staff per channel are needed, and to maintain their vigilance they need time to move around and to take breaks. It is typical to roster eight staff per channel in a busy time, and that becomes a significant number of staff. It is nowadays a significant proportion of the airport operating cost.

Once through the security check a passenger is 'airside', and they are not allowed to proceed back 'landside' without appreciating that they will have to renegotiate the complete security process again. Airport staff need to transit this invisible line many times daily, however, so a rule-of-thumb is that there should be one staff channel for every 8–10 passenger channels. These are also manned, and the checks have to be more than perfunctory to maintain a high level of security. It is usual to have closed-circuit television (CCTV) monitoring as many security channels as possible. Indeed, security cameras, on the outside and internally, are used at all main airports nowadays, with 20 or more cameras being a typical 'small' installation, even at an airport with perhaps half-a-million passengers per year. At a large airport there can be many hundreds of cameras, all with their images continuously recorded, monitoring operations. Cameras will be mounted within the terminal, over access roads and also car parks.

The departing passenger, after the hassle of check-in and security, is enticed to relax in the departure lounge. Concessions will be offered to businesses to supply food and drink, newspapers and incidental goods, even high-quality goods, and there will be the inevitable 'duty-free' shopping area. At large airports these facilities reach city shopping mall proportions, and the revenue they generate is often a vital part of the airport operator's revenue. The airlines, who value their 'high-yield' passengers, will not discourage them from cruising these areas, but additionally they will offer so-called 'business or executive lounges' where they can retire from the hustle and bustle of the departure lounge. They provide free refreshments, spacious and comfortable seats, and may offer a personal call-to-flight service. The ability to do work using laptops and internet links has been indicative in recent years of how the airlines will innovate to offer a better-quality service, but they have to pay handsomely for this space. These have not been the exclusive preserve of the departing service either, for in recent times airlines have hit on the idea of providing a reception service to disembarking passengers, where they can shower and change into laundered clothes, thus arriving fresh at business meetings. Airports dislike these continual calls upon valuable space, but can be encouraged to provide the necessary facilities when the appropriate charges are agreed. Overall, the

airport can become a significant proportion of airline costs for business passengers.

The final part of the departure process is the aircraft gate. In ideal circumstances this will be a lounge area near the aircraft. The passengers are called there by the 'boarding call' – which in some 'quiet' airports will be on the FIDS only – and congregate for the final time before leaving the airport. In some countries a final passport control check is conducted, usually on entry to the lounge, and finally they have to surrender all but the stub of their boarding pass as they pass out of the terminal building. Airlines are obliged to reconcile the boarding cards they collect with those issued, and the aircraft cabin crew will conduct a passenger head count too. This is all a part of the safety culture, unheard of on other modes of transport. It is vital in aviation to know exactly the 'souls on board', and if a passenger fails to board, the airline – even if it causes a significant delay – will unload and retrieve the passenger's baggage. This is not done in the name of service quality; it is done because the opportunity to load unwanted devices in unattended baggage has to be eliminated.

Most airlines vie to park their aircraft on a stand that has an 'air-bridge' (or jetty) to the gate lounge. This retractable tube can be steered to mate with the aircraft door, and at some airports the transition from terminal to aircraft is almost invisible. Where it is necessary to park aircraft on 'remote' stands, however, passengers embark and disembark using steps – either driven alongside, or are retractable from within the aircraft (sometimes called 'airstairs') – and are transferred between the stand and the terminal using buses. At airports where there are no air-bridge facilities passengers have to walk to/from the terminal and aircraft, which is potentially hazardous, so airport staff and airline representatives are forced to stand at strategic points on the route and erect temporary fences to prevent passengers walking into harm's way. All staff working on an airport apron have to wear a high-visibility jacket; at strictly run airports, failing to adhere to this demand is a punishable offence, and persistent offenders can be dismissed. All this is done in such a way that the majority of passengers never notice the procedures that are being invoked to ensure the safety of themselves and others.

Arriving passengers are directed to different doors from those where departing passengers will emerge. Where there are air-bridges, there are often adjacent fixed sections of the tubular walkway that gently slope down from the departure gate lounge or from the aircraft to the arrivals hall. The entrance to these tubes can be opened and sealed by the ramp staff. These are indicative of the detail that can characterise facilities that assist an airline's need to conduct a quick turnround.

The terminal processes that have been described have to be conducted strictly according to a timetable that is built around the scheduled arrival

and departure times of aircraft movements. If an arriving aircraft is delayed the consequence is that passengers will be left longer in the departure lounge and gate areas. Usually, an airport will not encourage the airline to call the passengers to the gate until they are certain of the movement's occurrence. There are two reasons: first, they keep the passengers in the most spacious part of the terminal and, second, they are kept where the concessions are continually accessible, as this all adds to airport revenue. Sadly, when delays occur that are not of the airport's making this can lead to great congestion, and it is ironic that an airport is often the beleaguered site upon which the media and passengers heap condemnation at such times. There are many airport staff who can recall heroic efforts to alleviate the effects of imposed congestion and whose efforts have been vilified rather than thanked. The airport, when under stress, is not a place where the faint-hearted should seek employment.

7.11 Airport demand, capacity and delay

Many of the considerations above have centred on capacity issues. The fact is that airports are notorious bottlenecks, and the reasons why, by and large, have been presented, alongside the fact that many of these reasons are outside their area of influence. Airports are treated as a resource, and thus can rarely ever be optimised, and yet they have to accept also that they are often the fall-guy for other people's inadequacies. While that is true in general, there are some fine and well-run airports, but finding one that is large and successful, and that is generally liked, is rare indeed.

When it does happen, and Singapore's Changi Airport would be the first on the list of customer-friendly airports, the fact is that the small state of Singapore grew by 4% just to accommodate Changi, and the market it serves has been economically buoyant and predictable, thus precipitating the airport's birth and supporting it throughout its life. The airport was also designed to accommodate the needs of Singapore Airlines, which gave the airport goals that they shared and evolved in consort. A similar symbiosis is evident in the way that the airline Emirates has worked with its base airport, Dubai, and that model seems set to be replicated again in Doha with Qatar Airways and in Abu Dhabi with the airline Etihad. So why did London Heathrow and British Airways or New York's Kennedy and the erstwhile Pan Am not hit on the same formula? The answer is they could not, if they were to be open to the free market. Every airline wanted to use these places and the two cities quoted had to resort even to multiple airports, which mitigates against efficiency for an airline if it has to disperse its resources across several sites. Kennedy had a set of terminals that some major airlines designed, owned and ran. This was almost unique, and it was not just wasteful but also a legacy that has caused considerable concern. Not least of

these concerns is that the emblematic TWA terminal has proved difficult to expand and yet is subject to a preservation order. Heathrow, on the other hand, having embarked on Terminal 5 will, in the wake of its opening, face few cries from preservationists when it begins to tear down the 1950s Terminal 2 in 2009. Changi, it has to be said, has remained 'open' and has served all comers well enough still to win praise, while serving Singapore Airlines perhaps best of all.

This review of what airports do, and what they have to respect in doing it, is by now a familiar tale, because like building aircraft or running an airline an airport has to balance financial viability, respect statutory obligations, be efficient and meet demanding service quality requirements that will be regarded overall as indicative of service quality. Capacity is at the heart of the efficiency arguments and effectiveness is one way of expressing the degree to which this aim is sometimes compromised in the quest for acceptable levels of service quality.

Delay is probably the most important quality-of-service indicator. Minimal delay is preferred, but attainable only at the price of having excess capacity (at other than peak times) and thus at extra cost to the airport user. In the competitive modern airport environment not all passengers are willing to pay the price. It can fall on the airport operator to find ways of accommodating high-price (executive or business) streams alongside the traditional 'mass' passenger handling facilities and charging the airlines a premium (which they pass on to the customer) for the privileges obtained. Some airports choose not to support this kind of service and make themselves attractive to 'low-cost' or 'no-frills' operators. While people tend to buy a ticket from an airliner and associate the product brand with that service provider, they too depend in many cases on suppliers and the airport is perhaps the most important of all.

Airports have particular dilemmas:

- While they do tend to be attractive to the community, people living close are likely to complain about noise and other forms of pollution, and yet people living further away will clamour for surface transportation links that assure them of good access (and that, in themselves, can be regarded as sources of pollution).
- Airports that serve tourism may be adjacent to areas of great natural beauty, but they must not destroy the qualities of what they set out to serve. Even so, airports have to be sited so that local terrain does not interfere with safe operations. In striving to ensure that adequate safety will be assured, limits are imposed that simply constrain the ability to operate them intensively.

While it is commonplace to demand that airports have to run as businesses, if the aeronautical revenue is limited, the only alternative is non-

aeronautical revenues. Many airports have become, in addition, places that will be used locally as shopping malls and business parks, to name just two popular ways of stimulating their financial status.

Nevertheless, the prime purpose of an airport is to offer air transport links that will serve the community. While few airports are developed from scratch, the criteria for selecting a site for an airport deserve some thought. An airport is generally expected to thrive if:

- There is a substantial local community.
- The economy is buoyant (population disposable income and age distribution data can be indicators crucial to success).
- There is good surface access from roads and public (rail or road) transport support (these can cause an airport to be favoured over any local competitor).

The check-list mirrors what any airline planner would muse over in looking at existing airports for regular scheduled service operations. Airports that depend largely on leisure traffic are equivalently attractive, but instead of looking at the total population an assessment should be made of local area access to leisure accommodation, the quality of accommodation and the ability of aircraft to reach regions from where holiday-makers would embark to use such facilitates.

An airport can also do a lot to boost its attractiveness to operators. It should consider:

- the 'quality' of its services (in simple terms the space, convenience and overall condition of facilities)
- the ability for airlines to carry passengers through on connecting flights (transfer passengers)
- the provision of cargo and freight aircraft handling facilities
- the provision of facilities for aircraft ramp maintenance and engineering overhauls
- the attractiveness of the airport as a major operating base for an airline, or airlines, acting perhaps as headquarters, and being the base for staff training, maintenance, etc.

If airlines take to an airport it will, subject to planning consent, soon begin to develop other roles, such as:

- attracting support businesses, which could be cargo forwarders, cargo distribution centres, etc.
- generating industrial development centres; warehousing and distribution tends to be pre-eminent, but could also be manufacturing (even aircraft production!)
- becoming a local transport interchange complex, where the network of

road and rail connections might eventually carry more local passengers than airport users and lead to a commercially attractive landside community.

Finally, if there is an overriding need for an airport – usually a socioeconomic need for a remote community – there is a possibility that it will survive under a subsidy scheme, whereby the national government regards the price paid to maintain an uneconomic business is good value for the community overall. Examples are Norwegian coastal airports and the Highland and Island airports of Scotland. This is not uncommon, but it can still be controversial.

This chapter has reviewed what airports set out to achieve and the tenets that will shape them as commercial and operational entities. To develop as airports they need to meet a number of requirements, operational in many cases and regulatory in others. This chapter has set out some of the main principles that govern how an airport has to meet the requirements for viability, compliance, efficiency and effectiveness.

8
Airspace management

Abstract: This chapter takes a look at airspace management systems, through perspectives that help to draw parallels with those that have been used in the aircraft, airline and airport chapters of the book. Airspace demand and capacity situations are among the most critical of the problems that have to be solved if the air transport industry is to continue to function efficiently and effectively. Such linkage has been generally too piecemeal, or elusive, using more single-discipline based analysis. The intention is to describe airspace issues in terms that relate to the situations that require consideration, and compromise, elsewhere in the air transport system.

Key words: categories of airspace, separation standards, airspace sectors, demand, capacity and delay relationships, functional evolution of ATC systems.

8.1 Introduction

Most aviation professionals fail to consider 'airspace management' in the same breath as the rest of aviation. The excuse is not one of disrespect but because it is a ground-based, and thus almost invisible, component of the air transport system. Originally it was called air traffic control (ATC), and ATC is still the preferred term with regard to the work that is conducted from airport control towers. This occupies a cab, atop the highest of an airport's buildings, and also requires an 'approach' unit. This is usually a room where radar screens glow and where much of the strategic and tactical work that complements the activities in the control tower is conducted.

ATC is more than that, and in the 1980s the phrase 'airspace management' was coined to cover the breadth of activities conducted at airports and in often unseen air traffic control centres (ATCCs) throughout the world. ATC service providers have always had a high proportion of their staff located at ATCCs, and although these usually started life in buildings on the

periphery of airports, nowadays they have often moved into parkland or on to an anonymous plot within a city industrial estate.

ATC was set up as, and remains, a service industry. Its mandate is to utilise and police the skies, ensuring (according to the original and long-held mantra of the business) ‘safe, orderly and expeditious flow of traffic’. In its early days, in the 1930s, it was never considered necessary to add the word ‘capacity’ to that description. The skies were regarded as a vast three-dimensional ocean in which aeroplanes could fly. An individual aircraft seemed insignificant in this enormous cavern, and the job was not to impede but to ‘control’ access to the sky and to assure flyers that they would be provided a separation service that would eliminate the risk of mid-air collision. The control element relied upon rules that would uphold the profession’s objectives, and these were formalised during the 1940s in ICAO Annex 11 (Air Traffic Services).

Solving the conundrums of the increasingly capacity-strapped en route airspace depends on more information, and thus more sophisticated sensors. As information flows in ever-greater volumes, the digital computer is used to help to digest and present that information with reduced ambiguity. The computer is a decision-support tool. Over time, circumstances have driven this role deeper, and now it threatens to reach into the decision-making regime. The implications, in terms of capacity and safety, and indeed the whole balance of power in the decision-making chain throughout the air transport system, are enormous. Purists might deplore it, but the route that has been followed, and seems sure to be followed, leaves little doubt about the significance of the changes that are about to take place. The questions that are difficult to answer are those that determine at what speed this change will occur.

Meanwhile, the humble airport-based ATC unit has seen plenty of change in the same era, but nothing is ever likely to change here to the extent that it will in ATCCs. In this chapter the way that ATC has evolved into the so-called air-navigation service provider (ANSP) network will be charted with an eye on each of the four objectives that previous chapters have drawn out from analysis of how aircraft are manufactured, and how airlines and airports are planned and operated. This is because ANSPs also have to be financially viable, to be compliant with international statutes (and more than any other part of the business, the air traffic profession is watching the statutory scene change almost more rapidly than they can react), to be efficient and to offer that effective (expeditious) level of service that has been central to its belief system from the earliest days. By the chapter end, the four main components of the air transport system will have been described in equivalent terms. The remaining chapters of the book will be able to look at the symbiosis between these components of the system.

8.2 Setting up an air-navigation service provider business

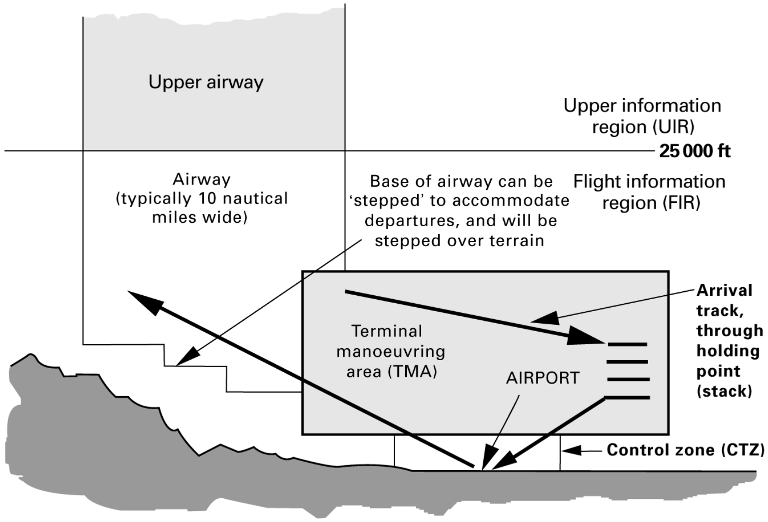
Initially air traffic control was seen as a public service. In the 1930s and 1940s nations did not look upon ATC as a, potentially, commercially viable business. The service was set up on a national basis to exercise control over the airspace in which the operator nation has been ceded ‘sovereignty’. How the limits of this airspace were defined was, and remains, a semi-political task. The need for redrafting of boundaries is not day-to-day work, but it is necessary when a nation subdivides, as has happened many times in the 20 years or so since the Soviet Union and neighbouring nations took independence.

Within the airspace, which is ‘controlled’ with regard to all air-breathing vehicles (officially up to an indefinite altitude, but clearly not extending into the vacuum of space), there are categories of airspace that are defined in terms of the service quality that is provided within them. There are seven categories defined in ICAO Annex 11, characterised as A through to G, with the highest level of service offered in Category A and the most basic service in Category G.

8.3 Categories of airspace

The subtle division of different segments within which aircraft are provided with different levels of service, while easy to draw on a map, are difficult to distinguish in reality. Navigating routes was initially a task performed using radio navigation aids, and these were sited and used in such a way that they aided aircraft to maintain a position within the sections of airspace allocated to them. Hence the shape of ‘airspace’ was linked directly to radio navigation aid location and performance, and the navigation aids (nowadays usually VORs with co-located DME – see Chapter 4 on the operational environment for a description of this and other navigation aids) have become the ‘reporting points’ through which flow has been monitored and controlled by ATC staff.

Airways are the routes, akin to aerial highways, along which airlines fly when cruising and during the higher level stages of climb and descent. In most cases they are 10 nautical mile wide and aim straight between radio beacons. The ‘base’ of an airway is always 1000 ft or more above terrain and rarely below 5000 ft above mean sea level, and extends up to 25 000 ft, and may even extend higher. These general rules allow space beneath airways in which aircraft can roam freely (and accept that a collision risk is present), thus allowing non-commercial aircraft to fly for pleasure. They usually accept responsibility for collision avoidance by flying under ‘visual flight rules’ (VFR), meaning that they fly during the day and stay clear of clouds. Within the controlled airspace commercial aircraft assume ‘instrument flight



8.1 Categories of airspace.

rules' (IFR), meaning that they will operate day or night and in any visibility conditions. This is important if airlines are to publish and maintain regularly timetabled services.

When aircraft are climbing or descending close to major airports, they are within a terminal manoeuvring area (TMA), or similarly designated block of airspace. In plan view this is often very irregularly shaped, and its vertical extent can vary with location, with no fixed upper limit, although 15 000–20 000 ft is typical. The TMA base is lower than the airways, but still at least 1000 ft above the terrain. Near the airports themselves, the controlled airspace reaches down to ground level, and the region is called a control zone (CTZ). A schematic diagram of these divisions is given in Fig. 8.1. The nomenclature and dimensions of airspace regions is subject to some national variations, and the description here is as non-specific as possible. Within airways, and in the TMA and CTZ, aircraft plan to fly along predefined routes, but may be vectored on alternative routes by the ATC controller in charge of the airspace. These are the highest category of ICAO airspace – Category A. This implies that all aircraft are subject to control, and as a consequence are assured separation from other traffic by the service provider. To be eligible for this service the aircraft must be appropriately equipped, with a range of redundant communication and navigation systems, and the crew must be licensed and trained to fly in all weather conditions and to be familiar with the range of systems on the aircraft type.

In the TMA the planned tracks to/from the airspace boundaries and airports within are called standard instrument departure routes (SIDs) or

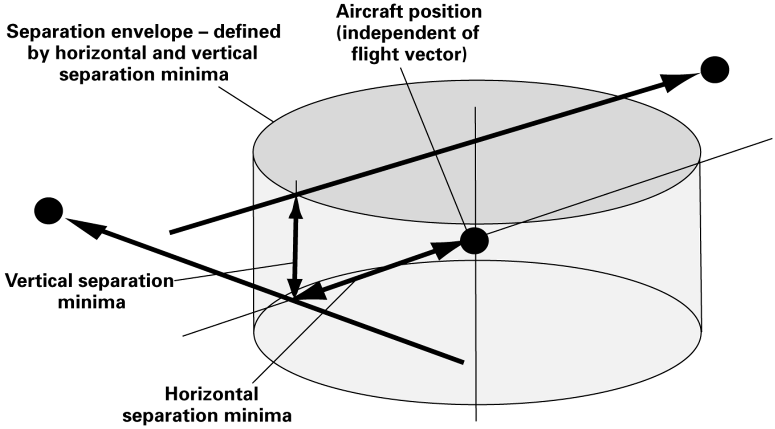
standard arrival routes (STARs). They are created within airspace planning departments employing specialists at the task, whose knowledge of operations must extend to knowing how instrument procedures affect aircraft in terms of manoeuvrability and performance, and who must also be conversant with the most minute details of navigation accuracy and ATC separation criteria. While these do not appear complicated, the detail within them is considerable. Once they are defined and published (in the national Aeronautical Information Publication (AIP)), aircraft plan to fly them, and the ATC service responsible for the route will issue 'clearances' in such a way that conflicts are avoided and capacity is used effectively. Outside airways, in the Category G airspace where there is no obligation to submit to control, ATC will often provide an advisory service. The shades between these two extreme conditions (in Categories B through to F airspace) are significant in operational terms, but they are not considered in depth in this description.

The SIDs and STARs serving individual airports tend to be the responsibility of the local ATC unit, the now familiar 'control tower' and the closely associated 'approach' radar unit. (It is important to note that the latter unit is rather inappropriately named as it handles both approach and departure movements and is especially involved in sequencing and handling arrival and departure traffic coordination.) The control tower staff also exercise responsibility for movements on the taxiways and the apron, so an aircraft cannot leave a stand until the control tower issues a clearance, and in turn they are unable to do this until there is an assurance from the local ATCC that there is capacity to accommodate the aircraft in the airspace it is about to join. Thus the airport is a servant to the ATCC, and while this has always been so, it was almost unnoticeable until the early days of jet operations, when en route airspace capacity first emerged as a serious service issue.

The remaining sections of this chapter deal with the mechanisms of ATC, handled in a simplified way, but as objectively as possible, with interest concentrated on their consequences for viability, compliance, efficiency and effectiveness. The way that air traffic will change in terms of the forces it will have to face (and uncertainty regarding the best solution likely to emerge) is then explored in the final chapters, and the mechanisms and scope of those organisations responsible for ANSP modernisation throughout the world will be revealed.

8.4 Separation minima

The concept of separation minima is at the heart of ATC operations. The principle is intrinsically simple; there should be a minimum distance between two adjacent aircraft that will never be infringed. The minima are expressed



8.2 Horizontal and vertical separation requirements.

as horizontal and vertical separation distances (Fig. 8.2). If the minima are infringed then the situation, even if there is no operational consequence, is regarded as serious enough to warrant investigation. This is done to determine if any lessons have been learned from the experience. For example, knowledge of the frequency of infringements can be used as evidence to refine the apportioning of risk to operating procedures. This is occasionally necessary, such as when refining separation standards as CNS system improvements are introduced. In recent years the results of incident frequency analyses have shown to regulators that further improvements in system positioning accuracy will not necessarily count for less separation without inviting an unacceptable increase in the collision risk, which is one source of capacity concerns.

International minima are set in ICAO Annex 11, and the national authorities in each country take on the responsibility to apply these. Sometimes they impose their own variations, when they have been ratified by ICAO. Horizontal separation minima were at first expressed in terms of time (always minutes) and vertical separation in terms of distance (e.g. 1000 ft). Horizontal distance minima (expressed in nautical miles) appeared when real-time surveillance, provided by radar, was introduced. As technology has delivered new capability, some of the minima have been changed over time.

Vertical separation minima will be discussed first. When these were first defined in the 1930s, they were based on the crew's ability to maintain a constant barometric altimeter reading. A separation of 1000 ft between opposite direction traffic in all circumstances was required, which applied up to 29 000 ft. In higher airspace regions (routinely used only after jet aircraft entered service in the late 1950s), the vertical separation criteria was

increased to 2000 ft, because the barometric altimeter is less sensitive in the more rarefied air. These conditions remained unchanged until the early 1990s. In 1990, when aircraft were appropriately equipped, in terms of higher accuracy height detection capability, reduced vertical separation minima (RVSM) standards were introduced that effectively extended the 1000 ft separation criteria into the upper atmosphere. This doubled the capacity of airspace in the normal jet airliner cruise regime and was a very welcome capacity development.

Consider next the evolution of horizontal separation criteria. Initially in en route phases of flight, time was used. The reason was simple. The ATC staff had no way of seeing the aircraft they were controlling (unless they happened to be very close to where the controller was located and the skies were clear). They depended on the crew navigating a predetermined route, which would pass over radio beacons, and reporting on radio when they were over the beacons. These became known as 'reporting points'. If a crew was setting off on a route between two points that were 75 nautical miles apart and were cruising at 150 knots, they could be expected to take 30 minutes to fly between the two points. The controller would acknowledge a radio report on passing the first point, at say 14:23 hours, and would expect the aircraft to report at the second point 30 minutes later, at 14:53 hours.

If another aircraft wanted to fly the same route, a 10-minute separation minimum was applied. No aircraft could fly the same route, at the same level, unless they were expected to remain at least 10 minutes behind the previous aircraft, at all points along the route. This was called *procedural separation*. If the first aircraft went ahead as quoted above and a second aircraft appeared, and it travelled at the same speed, it could pass the first control point at 14:33 hours, and thus would be expected to arrive at the second point at 15:03 hours. However, if it cruised at 225 knots, it could reach the second point after only 20 minutes of flying time, so if 10 minutes' separation was applied at the first point (meaning it passed there at 14:33 hours) its estimated time of arrival at the second point would be the same as the first aircraft. Clearly this would not be acceptable. The controller had to work out that the acceptable time was 15:03, and thus the first control point could not be crossed before 14:43 hours. The time separation at the second point was the critical aspect in terms of meeting the minima (10 minutes). Procedural separation was safe, but intrinsically it was wasteful in the way it allocated airspace, in that the flow that resulted was not orderly or expeditious. However, this did not have significant delay consequences while aircraft movements were few and far between, as faster aircraft were usually able to use a higher cruising level.

As radar was introduced, aircraft were allowed to pass one another using a horizontal minimum criteria based on distance while they were within the surveillance coverage of radar stations. In good circumstances this could be

5 nautical miles (as seen by the controller on the radar screen). It is important to bear in mind that the aircraft might be in cloud and totally invisible to one another. The system still did not let aircraft follow one another at less than 10 minutes' separation. (If 5 nautical miles was to have been substituted the time difference at 480 knots would have become a mere 37.5 seconds, which would beg the question of wake-vortex upset, and furthermore the system safety case would be in jeopardy overall if the one sensor that was relied upon – the surveillance radar – failed.) There was also the question as to how well synchronised the time-keeping systems were in different aircraft. However, if two aircraft were on opposing courses and separated by at least 1000 ft vertically, if the lower aircraft wanted to climb, the controller could now initiate that process as soon as he or she was assured, by radar surveillance, that the aircraft had passed and that there was at least 5 nautical miles of separation between them. The equivalent procedural process would have required the aircraft to reach the next reporting point that the higher traffic had already passed. Radar surveillance therefore improved en route airspace capacity enormously.

'In train' aircraft were spaced at 10 minute intervals, so safety considerations still limited the capacity of a level in an airway to just six aircraft per hour. There were circumstances when the separation was reduced, such as when aircraft were flying in regions where radar surveillance was continuous, and especially if the ground system had conflict-detection software that could determine the relative shift in longitudinal spacing between traffic. However, if this was not possible beyond the handover point where aircraft fly from an intensively monitored region to a part of the world where surveillance is of poorer quality, the separation criteria pertaining to the lower-surveillance quality region had to be applied. Interestingly, this situation has existed on all traffic bound between the USA and Europe, in both directions, because over an ocean area the ability to track aircraft has been non-existent. Almost all long-haul operations throughout the world, until recent times, have been severely compromised by these circumstances.

The above limitation could be about to disappear, as the introduction of autonomous dependent surveillance (ADS) effectively causes each aircraft to report its position every few seconds. ADS-B (the B standing for 'broadcast', meaning that data are receivable by all listeners and not just a recipient list) has been introduced over the Pacific and Atlantic Oceans and will soon revolutionise operations over deserts too. It allows ground-based staff to monitor aircraft in real-time, because the data-link conveyed position reports can be digested electronically and shown on a radar-like plan display. This is an example of where the capability that has been introduced under another heading – the operational environment (Chapter 4) – has played a significant part in rewriting the way that ATC solutions are

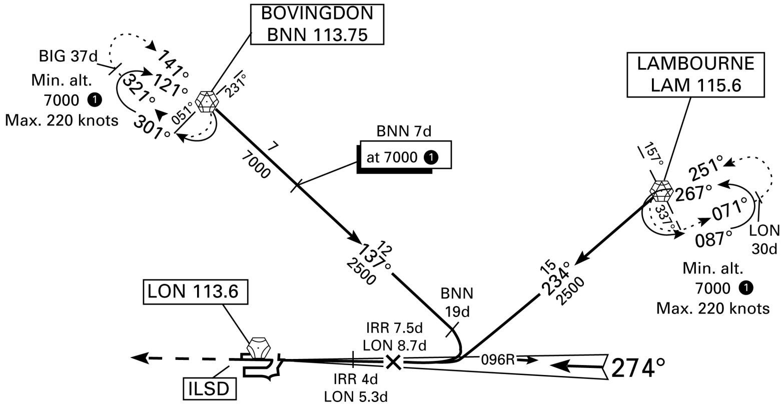
implemented throughout the world. This is a clear example of how the holistic approach to air transport problem-solving will bring benefits for users, even if the cost of implementation is their own to bear and the credit appears in someone else's domain.

The examples so far have applied to en route operations, but the same principles apply to operations in the vicinity of airports – the control zone and TMA. The way that aircraft are collected in and sequenced into a civil airport and the way that aircraft departing the same airport are threaded through the arrival traffic are the operations that set limits on the capacity of an airport.

First, arrival flows are directed towards an initial fix, and in the case of large airports there may be two or more fix points. These are the locations that are sometimes called stacking points, for if delay has to be introduced the aircraft will be instructed to fly a roughly circular pattern based on the point, which will tend to be a navaid location (invariably a VOR/DME). While beyond this point the aircraft will have a plan that says it will fly a standard arrival route (STAR), it will not normally expect to do so exactly, as from this point the aircraft tends to be sequenced by a controller using radar-generated information. (The value of the STAR is once again rooted in the safety culture. If the aircraft has a communication system failure, it will proceed according to the STAR procedures, and the ATC system will maintain separation by vectoring other traffic out of its way.) The approach service controllers at all but the very simplest of airports are radar-equipped facilities, and are allowed to vector 'in-train' aircraft according to the 5 nautical miles separation rule. The radar controller will create a line of aircraft and may even need to merge lines from more than one fix point in order to create a steady stream of arrivals to the runway. Figure 8.3 shows a set of STARs that are typical of those used to support the use of a busy airport runway.

The use of radar surveillance assures a similar level of approach flow rate, irrespective of the weather conditions. In fact, in very severe weather (Categories 2 and 3 low-visibility conditions are described in more detail later), the capacity has to diminish for the simple safety reason that post-landing the crew and visual ATC control procedures have to adopt wider time-separation criteria. During the approach phase the vertical profile of the aircraft is monitored, to bring it through the fix at an altitude that is usable at all times. Then the aircraft is descended, typically to between 1500 and 3000 ft or so above the airport elevation, as it joins the final approach path, which it will fly at a constant speed from about 10 nautical miles.

If the sequencing can attain a steady distance of 4 nautical miles between succeeding movements, and the approach speed is 150 knots (2.5 nautical miles per minute), the aircraft will arrive at 1.6 minute (= 4/2.5) apart. This is equivalent to 37.5 (= 60/1.6) arrival movements per hour, and is



8.3 Example airport STAR (London Heathrow, runway 27R) (Source: Racal AERAD (1999), now Thales). This is not a complete or up-to-date chart. Do not refer to for navigation.

attainable only if there are no 'heavy' (significant wake-vortex-generating) aircraft in the arrival flow. At commercial airports it does not get much better than that, and the controller team that facilitates this kind of operation is one that delivers tremendous value at the expense of great concentration. It is a task that is skilful and labour-intensive, but at the same time it is rewarding to those who do the job.

Meanwhile departures have to be accommodated. They can usually stream off a dedicated runway or be slotted between arrivals. In the latter case the attainable arrival capacity will usually fall, because the departure has to be airborne in time for the arriving aircraft to be cleared to land at a safe distance from touchdown. The considerations of this kind of operation have been spelled out in Chapter 7 on airports, where it was shown that capacity would be perhaps 40–45 movements per hour, at best, with 50% each dedicated to arrivals and departures. A departure-only runway can cope with up to 60 departures per hour. To achieve this it needs access to sufficiently free airspace, the traffic sample must be ordered in such a way that following aircraft do not catch up on preceding aircraft and wake-vortex issues must be handled without any capacity-impact implications. Thus a single runway airport can handle up to 40–45 movements in its peak hour, and an airport with independent arrival and departure runways can handle up to 37.5 arrivals and as many as 60 departures per hour. If an airport has more than two runways, the interactions between them, and associated with the airfield configuration overall, can achieve more capacity. It is ATC procedures that set these constraints. These are so closely allied to separation procedures, which have shown no inclination to exhibit improvement when automated systems have been used to replace

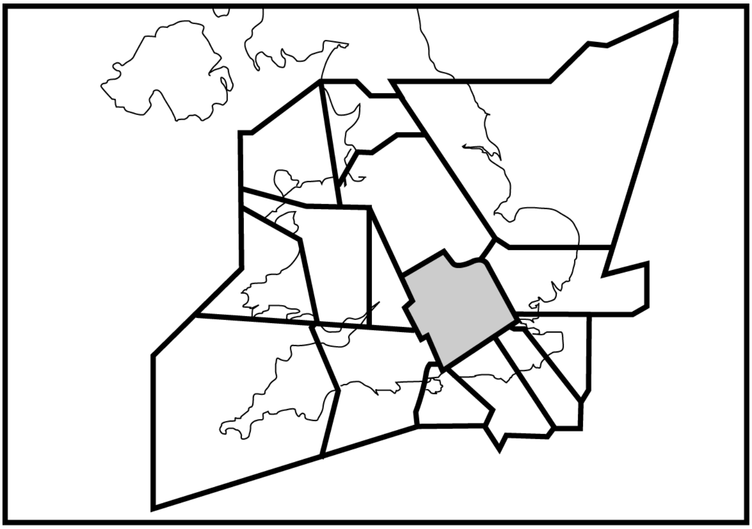
controllers, that the airport-based aspect of ATC seems certain to be capacity-capped at levels similar to those quoted forever. Although the research to date has suggested that the door is shut, there is still a desire to prise it open, and optimism continues to encourage investigation in some development teams.

8.5 Airspace sectors

ATC is about vectoring aircraft, and because there is so much decision-making involved it is a human based business, so the capacity of the human being to handle more and more aircraft simultaneously is a necessary limit on the capacity of ATC functions. Workload models are used to assess the capability of controllers put into certain control situations, and these are usually based on empirical evidence of capability that has been derived from assessment projects. If within a sector the simultaneous arrival capacity is assessed to be 15 aircraft and the typical path through the sector is 45 nautical miles long, the time that it will take for an aircraft to pass through the sector might be 10 minutes. This would indicate that 1.5 aircraft per minute can enter the sector – or 90 per hour. The longer the typical sector path, and the longer therefore the transit time, the fewer aircraft can enter in a given period of time.

Such an assessment depends on knowledge of the traffic configuration, with merging and crossing points causing the biggest reduction in capacity, which might mean not more than, say, eight aircraft on the sector simultaneously. In the situation considered already (10 minute average transit time) this would approximate to an aircraft joining the airspace every 1.25 minutes – or 48 per hour. If this is too low the sector size has to be reduced, meaning that an additional sector is introduced; thus more controllers are needed to handle the flow along a given route as it becomes more complex and longer. If there is no infusion of technology that will assist in handling higher levels of workload, the ATC staff levels needed to support a given region (an en route area or an airport) will inevitably rise as traffic levels rise. The rate of increase can be assessed empirically, but the inclusion of more and more 'handovers' between controllers means that a controller has to devote more time to communications within the ATC system, and the cost-effectiveness of services can often fall as traffic level targets rise. In Chapter 13, where modern data-handling techniques are described, their potential to break the mould will become more apparent.

The sectorisation of airspace is a complex planning task. Once a configuration has been determined, its planners will test its effectiveness by using computer-based simulations that require large facilities (and draw on controller resources). This is almost reason enough to resist the re-sectorisation of an ATCC, or TMA, region, but additionally there is a vast



8.4 Airspace sectors (Source: UK NATS).

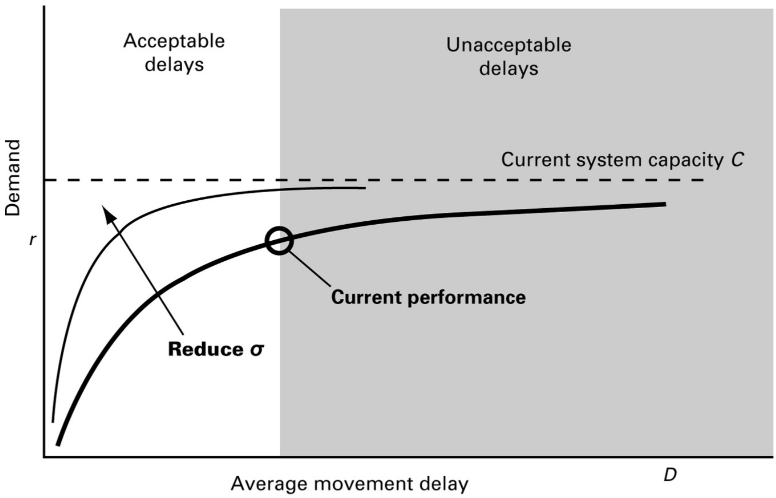
amount of re-training involved, and the new airspace procedures affect aircraft worldwide. Consequently, the process is applied sparingly, and when it does happen it will have been meticulously pre-planned and the new flight instructions promulgated widely with substantial warning. As an example of the complexity of this sometimes invisible configuring of airspace, a lower airspace sector map of London ATCC in recent times is shown in Fig. 8.4.

The inevitability that higher traffic loads mean more controllers are needed has been behind the gradual expansion that has been borne stoically by government-owned ANSP organisations over numerous decades. However, privatised businesses have greater difficulty in justifying their increased outlay per movement to customers who are shaving cost models to the bone. This is one example of where the privatisation model does not work as well within the ANSP sector as it does in the airline and airport sector. This has not been a deterrent to the off-loading of what is a capital-intensive business in many countries, however, and as the situation is not rigorously regulated, there is a fear factor associated with the expansion of privatisation policies into areas where ATC investment needs are substantial. This becomes more critical if there is a poor supply of qualified staff and a lack of ability to train people to use the latest systems.

8.6 Capacity, demand and delay

The most well-documented tool in the arsenal of ANSPs, when they come to justify choices that balance the desire for orderly and expeditious service within their area of responsibility, is illustrated in a traffic flow diagram, where delay, capacity and demand are all related. This is shown in Fig. 8.5. It is a graph that has numerous applications, such as describing the relationship between service, demand and queues affecting passenger flows through an airport terminal, or the way that surface-based transport systems – railways and highways – operate. Its applicability to airspace issues is no different, albeit this is a three-dimensional capacity issue with vehicles that cannot stop and can suffer perilously if they run out of fuel.

Essentially, the graph shows that the more orderly the flow (in which case the smaller will be the value of σ), the closer a system can run to its capacity limit while causing a given level of delay (averaged over all movements). If the demand was perfectly regular (implying that all aircraft were spaced evenly from one another), $\sigma = 0$, and the delay curve would rise from the origin, proceed straight up the Y axis (i.e. no delay at any demand level) and, as demand reached the capacity level, the line would go horizontally to the right. This is a theoretical solution, not least because aircraft (indeed any set of vehicles or individuals in a system) operate at different speeds.



$$D = \left(\frac{1}{1-r}\right) + \left(\frac{r\lambda + \lambda\sigma^2}{2}\right), \qquad r = \frac{\text{rate of arrivals } (\lambda)}{\text{system capacity } (C)}$$

where σ = variation in service rate
D = average movement delay

8.5 Capacity, demand and delay relationship.

Additionally, aircraft can be at different levels and can be affected differently by the weather, over time or over a region, and so on. In reality therefore, σ cannot equal zero, and there will always be a delay associated with a level of demand. That delay will increase as demand approaches the capacity of the system. In ATC, in aiming to meet the request for an 'orderly' flow, the system procedures assist in minimising the value of σ. The controller does this without the use of mathematical processes. It is through procedures that make appropriate use of the capabilities they have available and the application of specific rules that ATC has, consistently and over many decades, achieved good capacity/delay results.

The information at hand to a controller, and upon whose values decisions are made, is associated with various systems, which have changed over time. Examples have already been given in this chapter, with radar surveillance the most significant example of all. Continuing to resolve ATC problems while achieving acceptable levels of service provision is the major 'systems' issue that civil aviation faces in the future, and the technological capability that will be called upon is likely to be profoundly different in the future to that used in the past.

The newer systems will call upon CNS capabilities that have already emerged in the study of aircraft, airlines and airports, so this chapter is not a stand-alone story. However, it concerns the one area where civil aviation's future is most likely to flourish or fail. Note that Fig. 8.5 does intimate that there is an average delay level per movement above which system performance is regarded as unacceptable. The higher the acceptable average delay level is set for a given service variation factor, the more capacity can be attributed to airspace. This is a clear indication of trading capacity and service performance. The definition of 'acceptable average delay' is a vital research initiative, and increasingly it is among the most vital of all air transport capacity limitation variables. Where the line is set is more than an academic question, and the confidence in where it is and how the service variation factor σ is influenced will relate to topics discussed in later chapters, as the roots of the answers that are needed are not the property of the ANSP alone, but are often found deep within the user components of the system.

8.7 A brief chronology of air traffic control system evolution

The description so far has shown how the ATC system applies the procedures that have evolved over the last 50 years or so. The fact that the mechanisms of the ATC system have changed is also relevant to the rest of the story, because change has to be accommodated in such a way that a system can evolve. In the ATC profession there is less latitude for radical

evolution than in any other components. While airliners are being manufactured from newer materials, airlines are adopting new economic paradigms and airports are extending runways or razing old terminals to the ground, the ATC system has to change in a more incremental manner. This section expresses the way that many of the changes already enumerated have been implemented, and a point to savour from the four stages that are identified and described is that while the ATC systems in the busiest parts of the world have undergone all of these transitions, there are places where the first, and most elementary, stage is still the normal operating mode. Whatever the transition proposed to carry ATC development forward from Stage 4, it has to be compatible with the transitions from Stages 1, 2 and 3. This is a very significant system design task, which will require the cooperation and understanding of all air transport system stakeholders.

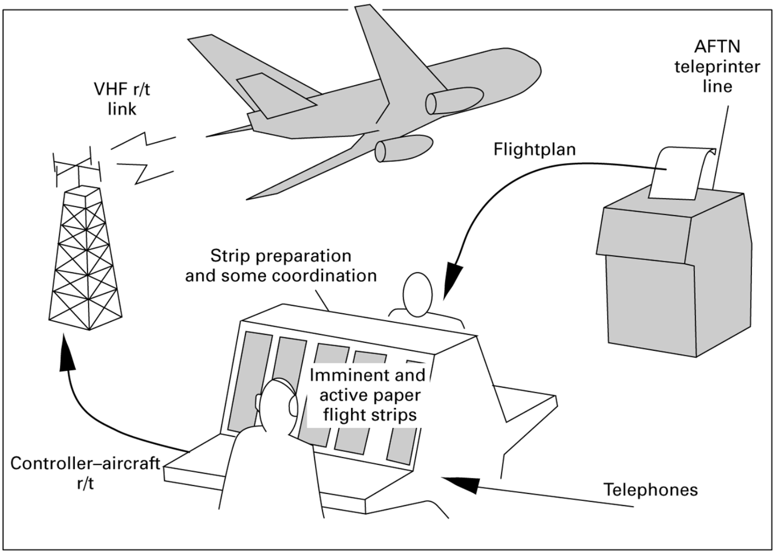
8.7.1 Stage 1: procedural ATC system

Stage 1 ATC systems use procedural methods. They require:

- that aircraft file a 'flight plan', a declaration of all relevant flight intentions
- a telecommunication system to distribute the flight plan to all relevant ATC units
- paper strips, at the ATC units, on to which flight details are written
- 'reporting points' over which aircraft report their positions as they fly their routes
- a radio system (invariable radio r/t) to communicate between aircrew and ATC units.

The region over which an ATC authority assumed control became known as the flight information region (FIR) and the routes along which separation was assured became known as 'airways'. The system depended on the adoption of an internationally recognised flight plan and the provision of a ground-based communication system, called the aeronautical fixed telecommunication network (AFTN). This has changed considerably over time, but has remained capable of supporting the same general requirements overall. The basic infrastructure of a Stage 1 ATC system is shown in Fig. 8.6.

There are two issues to appreciate in the human interface – 'display' and 'control'. Display is the function of presenting information in a way that is understandable to the person tasked to make decisions. Control is the function whereby decisions having been made, the instructions can be issued. It is desirable that the display function also allows the user to keep a record of the instructions issued, so that the controller – or anyone working



8.6 Schematic diagram of a Stage 1 (procedural) ATC system.

alongside – has a complete record of the situation. The information they get is called 'situational awareness'.

In this most elementary of systems, the most significant display element is a large rack on which paper strips, about 15 cm long and 3 cm deep, are held in special strip-holders. The flight plan progress strip (FPPS) has colours, which convey information (eastbound, westbound, crossing traffic, etc.), and data written on them, presenting such information as the aircraft's callsign, requested level, route and destination. A controller has a strip for each reporting point in their sector. This means that there will be a number of strips per aircraft, and the board of strips can only convey 'situational awareness' to an individual who is trained to interpret their data. Paper strips are beginning to disappear, but in many ATC systems worldwide this is still the preferred method of presenting and recording information. The paper strips are bundled and archived each day, and saved for several weeks, in case an incident requires investigation.

In terms of the route that an aircraft flies, the ATC controller is responsible for the 'clearance' and the aircraft crew are responsible for guiding the aircraft to where they are instructed. They follow the route and obey clearance instructions, which the ATC controller updates as the aircraft passes decision points. Aircraft are able to make requests and an ATC controller can re-clear an aircraft to a new route or to a different level, if the strips present evidence that there is space to accommodate the aircraft.

The mental picture of what the ATC controller and the aircrew in the airliner look at, day or night, good or bad weather, in their respective places

of work needs to be kept in mind. As ATC system development has occurred, it is these components and the way that they allow information to be used that will be seen to have changed.

8.7.2 Stage 2: procedural ATC with radar assistance

In the 1960s ATC began to use radar in earnest. Some radar applications had arrived after World War II, with surveillance approach radar (SAR) serving the aerodrome ATC units, which developed the 'approach' function using this system. The SAR radar was a short-range, relatively narrow field-of-view and fast-rotating, radar. The approach path could be seen on the screen, and the aircraft was a small target that could be guided. Some radar installations also had a vertical scanning unit, so that the plan and side view of the aircraft's progress down the approach was visible to the approach controller. This allowed 'talk-down' approaches to be conducted in low cloudbase on runways that had good approach lights, even if they had no navigation aids.

At airports that had ILS (Chapter 4) the radar could be used to monitor aircraft but was used more routinely to guide aircraft into the narrow beam of the ILS, so that the crew could establish a stable approach as soon as possible. Note that if SAR was used and there was only one radar screen, the operator took about 10 minutes to 'talk down' and then pick up the next aircraft to sequence, so the runway capacity was approximately 6 arrivals per hour. This was a big improvement on being shut because of low cloud, but the system did not provide as much capacity as busy airports wanted. Where an ILS was available to provide direct guidance to the aircrew, the approach radar operator now simply 'sequenced' aircraft to a point where they could acquire the ILS guidance signal. Movements could be monitored during their approach, and as aircraft could be brought in as close as was safely sustainable, the ILS solved the runway approach capacity problem many decades ago. This kind of operation has remained almost unchanged, apart from improvements attributable to 'daylight-viewing' radar displays and more sophisticated electronic data-exchange systems, especially between the airport and the local ATCC.

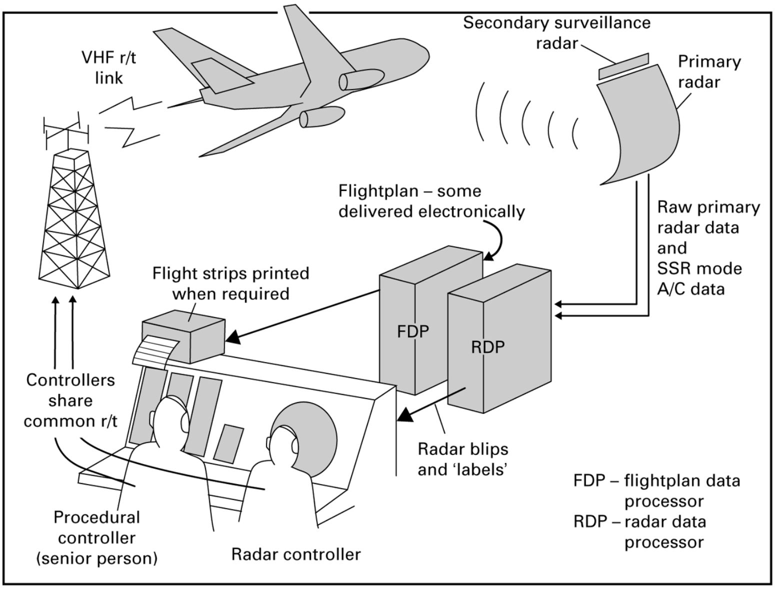
Within the ATCC the arrival of radar, while welcomed because of the surveillance improvement it offered, was more difficult to accommodate, because for many years the transfer of radar data by landline was regarded as too unreliable. Long-range 'area' radars were located in strategic positions (often for military purposes, and used on request by civilian ATC) and a controller located at the radar site could communicate directly with the ATCC procedural controller. These became known as the radar controller and procedural controller, but as computers and landline transmission of data improved this proved to be a transitory architecture.

There may be a few ATC units where this practice still exists, but no such unit would ever be built nowadays. The very least facility that will be considered is a system similar to that described in the next section.

8.7.3 Stage 3: the first–generation 'automated' ATC system

In the ATCC, radar and computers were combined, creating an installation that was a major leap forward in the way that radar provided real-time surveillance within the ATCC (see Fig. 8.7). Now ATC was no longer dependent on the periodic reports that were given over reporting points. Indeed, aircrew often no longer had to pass on such information. In addition to getting primary radar, which detects aeroplanes (and a lot more) and presents a 'blip', there was a surge of interest in the secondary radar. This could detect aircraft with an ATC transponder on board and determine a code that identified the aircraft and the aircraft level (primary and secondary radar are described in Chapter 4). These radars were placed strategically around the region and the information was encrypted on to a landline and sent to the ATCC. At the same time, the signal that had made teleprinters tap out flight plan data for many years was ideally suited to being read and interpreted by a computer. Two large computers were usually installed, and their functions were:

- The flight-data processor (FDP) collected the flight-plan data and kept



8.7 Schematic diagram of a first-generation 'automated' ATC system.

an up-to-date log of aircraft callsigns, the transponder code they were allocated and the route they would fly. The route information was used to print paper strips (no longer hand-written and often only one per flight per sector now) and the transponder code and aircraft call sign information was sent to the second computer (next).

- The radar-data processor (RDP) collected the primary and secondary radar data and 'mozaiced' (combined) the information from various radars, so that the controller was not limited to seeing a circle about one radar. So long as the radar could reach there, they could see into any part of the sector they controlled. The secondary radar collected each movement's transponder code and the FDP data were used to correlate this with the radio callsign. The computer generated a 'label' that was attached to the radar blip on the screen. Each relevant blip was thus tagged with a label that moved with it. If the secondary radar and transponder could determine the aircraft level, this information was also added to the label. It could include an arrow that showed if the aircraft was climbing or descending. It was common practice also to add a letter code, indicating where the aircraft was heading – to an airport in the region or an exit point into another region.

Two controllers, situated side-by-side, now cooperated. One handled telephone messages that told of aircraft coming into the sector, or originating messages elsewhere that told them to expect traffic; this controller was called the strategic controller. Roles included determining strategy, and this left the tactical controller to determine tactics, thus directing aircraft by issuing instructions or responding to requests on the radio. In reality the division of roles was not usually so clear-cut.

Most pilots were still flying in aircraft that did not have electronically integrated display systems, but aircraft were getting faster, the navigator has been removed from the flight deck and so pilots had to work hard to conduct navigation and simultaneously keep ATC informed of position. They had workload problems. However, even they benefited greatly from the secondary radar and transponder, as it kept the ATCC staff informed of their exact position – in three dimensions – and it could even measure their speed from successive radar contacts. The need for crews to pass information diminished and the utilisation of radio frequencies was considerably enhanced, especially in the TMA, where the majority of aircraft were climbing and descending and controllers benefited from having a greater proportion of time available to judge tactical moves and discuss strategic decisions with their partner. Controller workload was eased considerably by these developments and contributed directly towards capacity improvements that were very significant, but almost unheralded, in the 1960s and 1970s.

The controllers' workstations have changed dramatically. They had a radar display (it was sometimes upright and sometimes flat), and thus they had a real-time picture. This was what allowed horizontal separation criteria to be reviewed and the capacity improvements already described to be achieved.

While the synthesis of radar and computers did a great deal to improve the service attributes of ATC systems, the rate at which technology was infused into airliner flight decks, as described previously in Chapter 5, came along a little later. Aircraft with electronic flight deck displays and flight management systems simplified the interpretation of sensor information, and provided displays that improved crew 'situational awareness' very significantly. These systems were in almost 50% of the world jet airliner fleet by 1990. The ATC controller was often unaware of how confident the crews were of their positions, and having to apply separations that they felt they were able to monitor better was often imposing delays that brought rashes of crew complaints. Aircrews did care that failure cases were being taken into account, but they knew that the skies were still relatively clear and the clearances they were getting were not making the best use of the airspace capacity that was available. It was much more difficult to create an information handling and display system of equivalent quality for the ATC system, but around the late 1980s that kind of capability began to arrive in ATCCs.

8.7.4 Stage 4: current generation radar and computer-based ATC systems

Before looking at how the systems have evolved in recent times, the dilemma of en route airspace capacity and its only solution to date – flow control – needs some consideration.

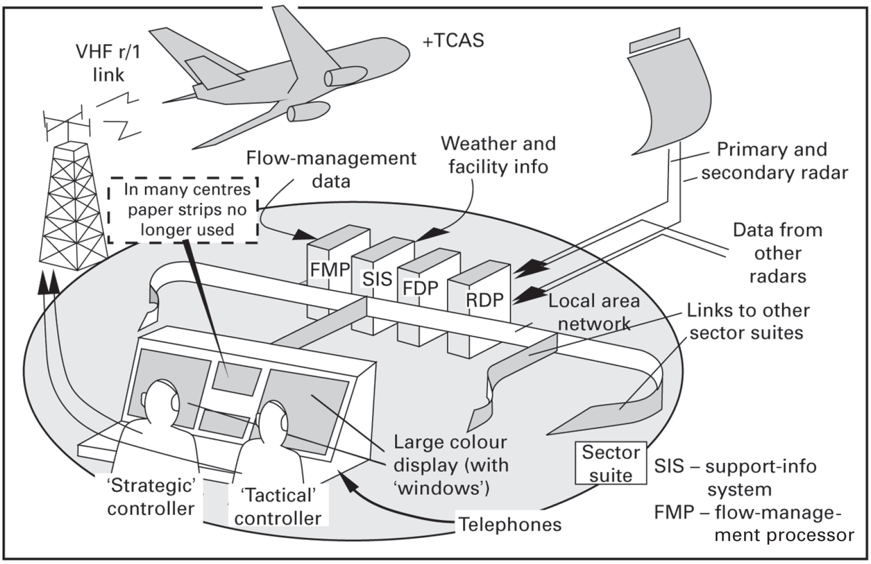
The effects of en route congestion were first seen in North America around the West Coast and East Coast conurbation regions in the 1960s. It was apparently a geographical issue, and there was some optimism that it was an issue of the time too, as jets and turboprops, and even a few piston-engine aircraft, with disparate speed capabilities plied the routes in those days, and this range of types certainly contributed to capacity dilemmas. Blanket speed restrictions eased a lot of capacity pressure, and even though this was successful, airspace planners recognised that capacity was a commodity that they would have to 'ration' to users. They began to plan for coping with more en route movements by collecting schedules as they were planned (perhaps six months ahead of the operation being performed) and to use computer simulations to forecast demand on busy routes. Eventually they began to model the whole of the continental US airspace. In Europe the

situation was growing as serious in the same period, and an equivalent flow assessment exercise became commonplace in its ATC research centres.

Behind the scenes, in that it was not a part of ATC as it was known, the flow-control function grew. It was manned by ATC staff, and their job was to assess demand and to redistribute it if possible or impose delays. This was safety over-ruling expeditiousness, and it was the most controversial ATC topic because it was apparent to all users that the airspace just was not 'full'. Flow control was eventually accepted as a component of the ATC system, and its presence in a system nowadays reflects that premeditation is exercised instead of handling aircraft 'first come, first served'. This development coincided with the introduction of the term airspace management.

A modern automated ATC system is illustrated, in a very schematic manner, in Fig. 8.8. The working practice established in the previous generation of systems has been retained, with 'tactical' and 'strategic' controllers, but now they work cooperatively, rather like the captain and first officer on a modern flight deck. The information sources are not very different to those shown previously, but some telephone routines have been replaced with digital message systems, for example, to hand over an aircraft between sectors or even ATCCs. The flight-plan data are taken via electronic links as the majority of plans are lodged many months before departure.

The FDP and RDP functions of the previous generation have had a flow-



8.8 A modern automated ATC system.

management processor (FMP) capability integrated, which works with the pan-national flow-management system (for the USA or Europe), and a support-information system (SIS) processing function was also integrated. The latter function handles weather forecasts and reports, as these also come via digital links.

There is little intrinsic difference in the attributes of the ATC service that can be offered, although the need to maintain a very strict procedural 'floor' has been abandoned, especially in constrained areas such as the TMAs. The paper strip has been replaced by electronic displays that can be as small as the previous generations' 'label', or expanded. This might be achieved simply by passing a cursor over a label, revealing a range of information that would have been on the strip in paper days. The radar-data processing complexity has been increased with integration of the conflict-detection probe. This is a device that evolved slowly through about 25 years (between 1975 and 2000).

The conflict-detector is a flight-path predictor tool and will work out where aircraft should be in the future – typically up to 15–20 minutes ahead. This is not easy to do in a busy TMA. If a potential conflict is detected, the system will alert the sector controller, who is obliged to address the conflict with an acknowledgement and probably a re-clearance to one or more aircraft. In its early incarnation this tool was disliked. It was seen to be 'big brother' watching over the controller. That negativity was dispelled with some careful development that is a milestone in human–system interface design. More importantly it has been accepted because it does keep an eye on the controller, who can be stressed by time-related circumstances. ATC controllers are not automated individuals. They have good days and bad days. They have traffic flows that are good some days and bad other days. Either scenario is a frustration, but put the two together and throw in some lousy weather to boot, and the potential for a catastrophic event escalates. The conflict-probe will not so much add to the controller's worries as alert them, and others (including their supervisors), that this is a situation that needs to be brought back towards a more manageable set of parameters.

There was a concern that, one day, ATC would rely on such a device to such an extent that it would be unsafe if the device failed. It was a fair supposition in the 1970s and 1980s, but around 1990 a new airborne device came along – traffic conflict and alerting systems (TCAS), which have been described in Chapter 4. This is autonomous and is designed to alert a crew to an aircraft coming dangerously close and to suggest a suitable avoiding action. Its parameters are more constraining than the conflict-detection probes used in the ATCC, and as such it is a 'belt and braces' (or classic example of a dissimilar redundancy solution) to a very critical safety case. TCAS has been mandatory on almost all air-transport aircraft since about 1990.

The way that ATC systems have evolved, creating capacity that has been so readily soaked up, and yet maintained a consistently high quality of service, against safety, orderly and expeditious requirements, has been a largely unheralded success story.

As the next stage of the book takes a view across the whole panoply of aircraft, airline, airport and airspace issues, the way they interact and how they can be used to combat or restructure limitations. It is suggested that the doomsayers can expect to find no comfort. There is every indication that the technology that will be needed to assist in this task is already on the shelf or close at hand. It is a matter of developing the skills to know how to present capability to relevant stakeholders across all elements of the air transport system. They need to be shown the 'big picture', which will be the air transport industry's 'situational awareness' test.

8.8 Aerodrome air traffic control equipment and operation

It has been commented that airfield ATC units have not undergone the same scale of development as ATCCs, but the equipment they use and the results they post have been achieved through a lot of procedure development.

The way that airfields operate when low-visibility procedures (LVPs) are in force deserves a special mention. Pre-radar, aircraft had to find their own way down the approach to a cloud break that would typically be at several hundreds of feet, even over a flat aerodrome. The capability to vector using radar, which came along post-World War II, and then to vector on to an ILS and to monitor the approach, in the early 1950s, has been explained. The ILS was the approach aid that suited all needs, although radio electromagnetic spectrum congestion did threaten to see the ILS usurped by a device called the microwave landing system (MLS). This development has not transpired, however. The ILS was, and still is, used as the main guidance source on landing for aircraft. It is often linked through the automatic flight control system (AFCS) and can even incorporate automatic landing capability. ILS allows the crew to descend, with confidence, in much lower-visibility conditions than they are allowed to fly through when handling the aircraft manually. It assures the crew that they will emerge from the cloud base exactly in-line with the runway centreline, or even be delivered right into the runway if the visibility is truly atrocious. Three distinct sets of approach operating minima are defined for aircraft approach operations in low-visibility conditions. These are:

Category 1. These are operations conducted when the cloudbase is not less than 200 ft AAL and the RVR exceeds 600 m. These are decision height

and visibility minima applicable to a competent aircrew conducting a visual or radar-assisted approach.

Category 2. These are operations conducted when the cloudbase is not less than 100 ft AAL and the RVR exceeds 300 m. These are decision height and visibility minima applicable to a competent aircrew conducting a visual or radar-assisted approach, with flight-director assistance, or a Category 2 cleared automatic flight control system. A go-around (missed approach) can be instigated at down to 100 ft in height.

Category 3. These are operations conducted when the cloudbase is below 100 ft AAL and the RVR is less than 300 m. There is no decision height and the crew has to be assisted by an automatic landing system. There are three weather minima subsets in this category:

Category 3a: 100 ft maximum cloudbase/300 m maximum RVR
Category 3b: zero ft decision height/75 m maximum RVR
Category 3c: zero ft decision height and zero m RVR – total fog.

(Note that the runway visual range (RVR) is a definition of visibility on a lit runway in fog and can be regarded as 1.5 times the reported meteorological visibility. Decision height and cloudbase are also linked in a similar way.)

Automatic landing had shown that such landings were possible as long ago as the mid-1960s, but it was only in the 1980s that the systems were widely used. They required aerodrome ATC operations to be equipped with their own very sensitive aerodrome surface movement radar (ASMR) or, in the classic safety case, they could only allow one aircraft to move on the airport at any time. It was soon possible with ASMR installed at all major airports in Europe and in North America to operate almost routine timetables in even dismal fogs. The aerodrome lighting of the approach, runway and taxiway has to be of a high standard, and the workload for controllers when they are managing a number of aircraft simultaneously is considerable.

Overall, at airports, the ATC function has evolved to ensure that capability limitations determining runway and airport capacity are only a constraining influence in the most severe weather conditions. It has therefore been in the en route control regime where attention to capacity limitations has been concentrated.

8.9 ICAO future air-navigation systems

The capabilities of some of the emerging, and as yet relatively unused, technologies have not been neglected. At this unique point in time some very fundamental work has been taking place in committee rooms and been implemented in laboratories over the last 20 years or so. Many of the

systems owe their presence to outcomes from the work of the ICAO future air-navigation systems (FANS) committee.

The FANS committee was not set up to solve ATM's problems. ICAO was aware that ATC systems would need to evolve and sought to define a functional framework – not a definitive system – within which new operational concepts could be enabled. The committee comprised representatives of aircraft and systems manufacturers, regulatory authorities and airspace users, as well as ATC staff. They were people who had the best knowledge of CNS developments.

When the committee was formed, in the late 1980s, the state-of-the-art in these fields and the emerging capabilities were thus:

- *Communication* was routinely provided by voice radio (either VHF or HF), but there was increasing use of digital data-link (such as Mode S) and satellite voice communications over oceans and sparsely populated regions. It was an objective of the FANS committee formally to identify how these developments would be integrated in future operations.
- *Navigation* could use one of many techniques, but it was generally reliant on ground-based radio navaids (such as VOR/DME and ILS) overland and around airports or inertial navigation systems (INS) when over oceans. The advent of satellite-based navigation systems, and especially global positioning systems (GPS), in all regions of airspace was forecast, and its imminent emergence from laboratory to flight decks was a large part of the focus for the FANS committee.
- *Surveillance* was still usually achieved by radar, either primary or secondary (ATC-transponder based/SSR Mode A/C), but there was increasing awareness and preliminary trials of autonomous dependent surveillance (ADS). Applications expanding to cover almost all oceanic regions were forecast, and given there was no surveillance at all in those regions at that time (but areas of congestion created by almost 'procedural' based ATC implementation), the need for change was apparent to the FANS committee.

A misnomer of the committee is that its name suggested a preoccupation with navigation, whereas it had a remit to view the complete CNS system development process. How it addressed the many technical and operational issues that were explored in a decade or so of prolonged and often very deep debate can only be summarised by taking a very general view of the conclusions it drew.

Satellite navigation, of which GPS was just one implementation (many others have emerged since), was viewed as a position-fixing system, but the FANS committee resisted the temptation to herald it as something groundbreaking. GPS did offer the opportunity to know position so accurately (within 5 metres anywhere on the Earth's surface is achievable) that the

committee had to challenge every aspect of limitations, including failure cases.

In traditional safety-led style they concentrated on investigating the 'integrity' of the system. They asked questions such as 'can GPS fail?' and 'If it does fail, what are the consequences?' Referring to legislation that has been discussed earlier they reasoned that the failure had to be 'minor'. This is a vital interpretation of safety legislation, for if every aircraft had to depend on the GPS satellites for position data, if the system so much as faltered, every aircraft could be left unaware of its position.

The US Department of Defense (DoD), who had sole responsibility for the provision of GPS as a navigation service, had to submit to ICAO very detailed evidence of the failures that could occur. The probabilities of occurrence were assessed and legislation for the certification of it was drafted. (The legislation also covered any consequent system that offered a signal-in-space (SIS) that was generated from multiple sources, in orbit or otherwise, and that depended on a provider's monitoring system to assure its integrity.) This is now international law and all subsequent systems, such as Glonass, EGNOS and Galileo, have had to undergo the same scrutiny.

The international law expresses what can be called minimum navigation performance specifications (MNPS). These are not new as they were used to authorise the application of INS in situations that had led to 'procedural' separation improvements in the 1970s.

That is the technical benchmark. Attention was also paid to the cost of these systems as they require huge investments. They dwarf most other technical projects, being long time-scale development programmes that will absorb billions (in whatever currency is assumed) and once they are in use the provider will incur operating costs that are equally massive.

To run a satellite-based navigation system, which has typically 24 satellites in orbit at any time, requires the operating authority to launch new satellites continuously. They are relatively large and have to be inserted in high orbits, so they need considerable power to do this.) The satellites have to be monitored, with a full diagnostic check completed on every satellite in every 12-hour period. The safety cases depend on the latter, because any fault has to be recognised and eliminated or neutralised in a specified time frame. It is all very 21st century capability, but is built on existing technology – indeed, often quite old technology (in electronic systems terms) – so that there is adequate confidence in the quality of service these satellites will offer.

The availability of position information of superb accuracy, anywhere worldwide, and the ability to capture or transmit real-time information in an almost continuous stream will affect the way that aircraft are navigated and how they communicate and operate. The flight management system (FMS), described in Chapter 4, will have better quality information than hitherto,

and will be able to present information, either on its own screen or directly on to the primary flight instruments, that will ensure awareness in more complex situations than could be envisaged and used. In addition to generating steering commands for the AFCS, it will generate warnings if the aircraft is not proceeding according to plan, for example if fuel is being consumed faster than expected. The aircrew, who use the FMS to examine the implications of ATC clearances, will find they are provided with precise advice on the clearance or re-clearance they should request. In some cases the information might be passed to the ATCC automatically, using the latest digital data-link, and the response, received by the same route, will flash on the aircraft's primary flight displays and will be poised for entry into the FMS algorithms, when the crew say they want to use that input.

TCAS will determine if another aircraft is close by and poses a potential collision threat, and thus provide an independent monitor to the ATC system. Meanwhile EGPWS, because it can detect and predict ground terrain, will enhance visualisation of potentially hazardous situations. In recent times the PFD has a terrain-awareness warning system (TAWS) incorporated, that provides a two-dimensional – plan and side elevation – view of the flight path (presented equivalently as it is on the paper maps and approach charts that crews have used throughout civil aviation history), thus aiding a crew's perception of the situation. The mass of paper maps that has traditionally filled crew flight bags seems destined to be reduced to the content of an electronic memory chip. Aircraft and ATC system evolution is entering new territory.

The ICAO FANS committee has been a systems integration point, where legislative content has been defined from rigorous and systemic debate. It has been the important shelf on which air transport system operations will sit for the foreseeable future and, if the committee has done the job really well, until beyond the lifetime of newly recruited current staff.

8.10 Air-navigation service providers as businesses

Moving forward into the current era, the air-navigation service provider (ANSP) role has been revealed to be one of the government-run agencies that are expanding, in terms of workload, and thus branded as an element that is suited to being 'privatised'. Several nations have done this, some whole-heartedly and others more circumspectly, retaining majority equity in the government or, if relinquishing financial control, retaining boardroom control. This is circumspect when a nation appreciates that the implications of a failure to perform have a potentially major impact (some would quote risk-assessment nomenclature 'chapter and verse' and upgrade that to catastrophic impact) on national economic performance.

There is no denying the fact that airspace management is vital to the

capacity of airports overall, and while it has an apparently vast working arena, it is capacity strapped. Therefore, while making money from current operations – enough at least to cover operating expenses – ATC authorities are rarely in a position to handle the research and capital costs of upgrading their systems, year on year. There are other coefficients in the equation. One that must be mentioned, but will not be investigated in depth, is the way that civil and military operations are jointly handled and the way that prioritisation of use of airspace is managed in times of conflict in particular. The major coefficient, and one of which it can be said unkindly, in Europe that has been swept under the carpet for over 40 years is pan-national ATC service coordination.

The will to do something about this situation has been there since the creation of Eurocontrol in the 1960s. The forces that shaped this organisation at its foundation were very different to those that shape its actions today. Some would say they leave it with a doubtful legacy; others will point to the fact that much has been learned, good and bad, along the way. There will be time enough to reflect on these points in due course, but more than any other organisation in the world, Eurocontrol is now at the hub of air transport 'system' optimisation. Its ability to achieve wide-ranging aims will have an impact on all those who use European airspace, which can mean aircraft operators and thus their customers from world-wide.

Eurocontrol's plight is not unique, however. In continental USA, where the scale of operations and the density of movements in the most well-used regions is still considerably greater than anywhere else in the world, there has been much less of the hubris that has been attached to equivalent development in Europe. The reason for this is absolutely simple. Continental USA is a swath of airspace that is similar in scale to Europe, and it is managed by one authority, the US Federal Aviation Administration (FAA). There has been no move to 'privatise' US air traffic affairs: they remain resolutely on the government agenda. It is in Europe, where 40-odd authorities apply their stamp of approval over 'sovereign' airspace, where 'privatisation' has been rife and where fragmentation has delayed progress. Within Europe, initiatives that currently culminate in the Single European Skies (SES) programme represent a salient point in time for Eurocontrol to display the ability to be an intellectual stakeholder in the regimes that evolve in due course. At the present time, only the USA and Eurocontrol are in a position to postulate and implement the kind of radical shifts in the ATC paradigm that seem certain to be necessary to solve impending capacity crises. Meanwhile, China and much of South-East Asia gear up to handle equivalent levels of traffic in similar-sized regions. This means that they will either copy the USA, look towards Europe (which being pan-national should be able to offer advice) or do their own thing.

American researchers have canvassed in Europe and worldwide to seek compatriots and have sown the ideas for collaborative development, but the uptake has been unimpressive, largely because of the fear that 'what is good for the goose is not necessarily good for the gander'. There is a fear within many of the establishments that have vested powers of authority over ATC affairs that if the world subscribes to the US paradigm, it will become subservient to their businesses too. Remedying this fear will mean that many deeply entrenched organisations must take a holistic view of the whole system, and fast. Their new perspectives have to be across the whole of the air transport system. This is difficult to achieve in any long-established organisation, but if the management of vital elements has disappeared into foreign or pan-national ownership, and the political will to commoditise economic needs and technical skills is no longer at the centre of the strategic decision-making process, it becomes burdensome.

This chapter has dealt with the mechanisms of ATC, with interest concentrated on their consequences for viability, compliance, efficiency and effectiveness. It has been acknowledged throughout that the way that air traffic will change, in terms of the forces it faces, and even not knowing what is the best solution that will emerge, is about to be explored. A point to stress is that these views are well understood in organisations already mentioned (FAA, Eurocontrol, and associated research and academic establishments, to name only the core) and have been well represented in papers from aircraft manufacturers (Boeing predominantly and Airbus with conviction, but less vigour).

Airlines and airports have tended to be hostages to fortune, being more concerned with day-to-day performance and acknowledging that the physical capacity of their direct contributions to the system are a part of the whole and largely examining proposals for acceptability rather than contributing to the establishment of workable solutions. In that 'interference', in terms of impact on the services they provide, has been clearly significant over time, their perspectives have been attributed a great deal of attention throughout this book. Their willingness to contribute has never been questioned, but their ability to explain their own paradigms with as full an understanding as is necessary for other stakeholders is questionable. There is more to airlines than the glib categories so often quoted, and likewise airports are more than just 'regional' or 'international'. They have strategies that will encourage all the stakeholders to take note of impact on their own domains.

The one stakeholder with the most difficult balancing act at this point in time (and perhaps indefinitely) is the ANSP. It has been with ill-founded timing that financial viability has been accelerated up the chain of priorities on the ANSP agenda, through the application of policies that fall neatly, in the political sense, under the heading of 'privatisation'.

9

Coping with change: in the environments

Abstract: This chapter opens the final phase of the book, and attention is devoted to the way that the air transport system will change. The natural, regulatory and operational environments used to describe the arena in which operations take place have been in continuous flux. Through available forecasts, the way that the environments will continue to change and exert an influence on the system's elements is discussed. Overall the environments set new goals that the elements will have to meet. Solutions meeting the criteria desired will require collective ownership of solutions, not one taking demand from the others.

Key words: global forecasts, capacity and demand changes, safety-related constraints, environmental impact considerations.

9.1 Introduction

Mention 'environment' and populist fervour is reserved for the detrimental effect that industry has on a multitude of atmospheric equilibria that impact natural life. Civil aviation usually gets a special mention, its effects being so direct on the atmosphere and its service regarded by many, unrealistically, as pure luxury. The question of environmental accountability will come later, but first the structure of the earlier chapters, where 'environment' has been addressed quite differently, will be addressed. Within the earlier chapters 'environment' has been a term used to describe what goes on around air transport, and it has been structured through debate regarding natural, regulatory and operational environments.

9.2 Natural environment

This concerns the Earth itself, and in particular the population, from which people seek a service from air transport providers. This is demand, and the overall demand for aviation services has to be considered in the context of

Table 9.1 Traffic within regions in 2025 (billions RPKs) (Source: Boeing Current Market Outlook)

Traffic within regions in 2025 (billions RPKs)					
2370	**1940**	**1090**	**360**	**90**	**90**
ASIA – PACIFIC	**750**	**800**	**9**	**240**	**17**
240	**NORTH AMERICA**	**940**	**400**	**50**	**18**
270	*390*	**EUROPE**	**400**	**200**	**300**
2	*150*	*150*	**LATIN AMERICAN**	**-**	**9**
80	*14*	*80*	*-*	**MIDDLE EAST**	**50**
5	*4*	*110*	*2*	*16*	**AFRICA**
690	*950*	*580*	*100*	*30*	*30*
Traffic within regions in 2005 (billions RPKs)					

Numbers in shaded boxes show traffic between region in *2005* and **2025**

the world population. As the populations in nations grow, so too does demand. Furthermore, as societies become more prosperous and as the cost per unit of air-service provision decreases, demand is again stimulated towards higher levels. On the whole the expectation is that GDPs in developed nations will grow less slowly than in developing nations. If there is an increase in the average GDP per head throughout the world, according to past experience, more people will fly, and on average each will want to fly more frequently.

The best available indicators of the expectations are provided by the long-term aircraft sales forecasts that are prepared and distributed on an annual basis by the leading aircraft manufacturers. The Boeing and Airbus forecasts look approximately 20 years into the future, and they were (at 2006) expecting demand for airliners to continue to increase, year on year, throughout the periods they have considered.

Table 9.1, extracted from the Boeing Current Market Outlook, shows the assessed demand in revenue passenger-kilometres (RPKs) for 2005 and the expected data in 2025. Demand within regions has been factored according to the anticipated demand growth in the 20-year period. The Boeing assessment of the impact this will have on demand for aircraft of different sizes is presented in Table 9.2, and it will dismay many with 'green' credentials that no fewer than 27 210 new airliners are expected to be delivered between 2005 and 2025.

Table 9.2 Deliveries by regions (Source: Boeing Current Market Outlook)

Size	Asia-Pacific	North America	Europe	Middle East	Latin America	Africa	World
Regional jets	580	2040	450	60	260	60	3450
Single-aisle	4230	5880	4530	430	1220	250	16 540
Twin-aisle	2520	1410	1460	540	190	110	6230
747 and larger	570	160	160	80	10	10	990
Total deliveries	7900	9490	6600	1110	1630	430	27 210

Table 9.3 New passenger aircraft deliveries by regions and passenger fleet development (Source: Airbus Global Market Forecast reports)

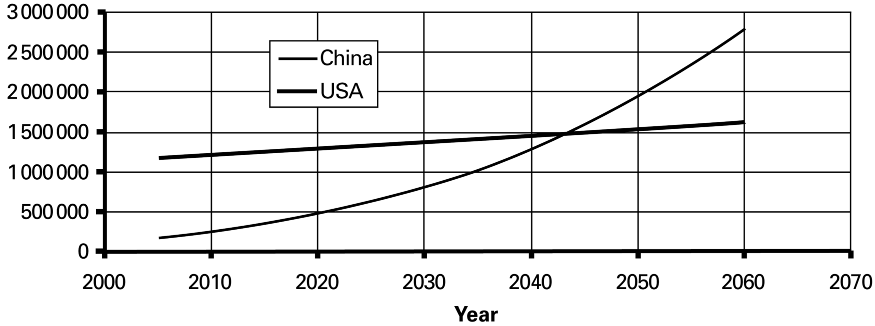
New passenger aircraft deliveries by regions

	Africa	Asia-Pacific	CIS	Europe	Latin America and Caribbean	Middle East	North America
50 seat	7	268	34	291	97	7	500
70–85	87	370	281	907	95	28	1016
100	73	173	46	625	275	42	772
125–240	317	3759	387	3407	916	305	4233
Small twin-aisle	152	1367	65	885	30	339	769
Intermediate twin-aisle	47	735	43	358	169	138	171
VLA	29	708	7	292	8	116	103

Passenger fleet development

	Fleet 2005	New aircraft deliveries 2006–2015	New aircraft deliveries 2016–2025	New aircraft deliveries 2006–2025	Recycled	Stay	Fleet 2025
50 seat	3426	490	717	1207	1394	291	2871
70–85	1051	1099	1695	2784	269	249	3901
100	1544	989	1017	2006	382	62	2460
125–240	8025	6476	6848	13324	4106	452	17882
Small twin-aisle	2126	1738	2007	3745	263	69	4077
Intermediate twin-aisle	856	747	775	1522	91	22	1635
VLA	25	499	764	1263	0	0	1263

Boeing is not alone in suggesting that the future is very bright for aircraft manufacturers. The Airbus Global Market Forecast, also published annually, presents a similar view of the world demand for airliners, and as Table 9.3 shows, expects that the 17 035 in service in 2005 will swell in numbers to 33 480 by 2025. It is not the news that 'environmentalists' want



9.1 Annual forecast passenger-km flown (millions).

to hear, but it is the most honest evaluation that can be obtained from the methodical analysis of the inherent demand for air transport operations that can be generated from economic indicators.

These are predictive assessments, and certainly not guaranteed to be the truth. Unexpected travel curtailment through legislative measures or economic impact, triggered by natural or man-made causes, could deflect the demand curves, flattening them or curving them downwards. As an example of the difficulties involved in long-term forecasting, Fig. 9.1 is a plot of the annual passenger-kilometres flown, extrapolated for the USA and China.

This plot has been created by assuming that annual passenger-kilometres per passenger in the USA is held level. This is onerous, but it is indicative of what the most draconian of prospective travel-curtailment legislation might achieve. Overall demand still rises because of a population growth trend (even though there is a diminishing rate of growth per annum). In China, while population growth predictions are much less than has been observed in the past, simply extrapolating the trend in passenger-kilometres per head of population usage, based on ICAO statistics between the late 1970s and 2005, predicts tremendous civil aviation growth. By 2025 Chinese civil aviation demand, while currently barely one-tenth of the US level, will have grown to about one-half, and if these predictive parameters are unimpeded by legislation, air transport demand in China will be greater than US consumption sometime in the early 2040s.

Note that the consumption of air transport service per head in China will still be considerably less than that in the USA. Given that Chinese GDP per head may have risen to US levels in this period, and thus disposable income will have reached similar levels, the propensity to travel in China will, without legislative constraints, almost certainly exceed the healthy growth shown. The actual level of air transport demand therefore seems set to rise, and considerably if unchecked by legislative procedures. It will still rise

significantly even if regulations that will artificially limit demand are imposed. This has tremendous implications on how airline, airport and airspace services are planned for the future.

The purported desire to implant 'green' credentials into the hearts and minds of all nations will, if successful, curb some of the demand increases, because it will limit the economic growth of nations, thus reducing prosperity – or at least reducing the rate at which prosperity grows. This kind of development, while affecting aviation demand indirectly, will almost certainly have a greater impact overall on air transport demand than direct actions, such as capping the capacity of the system.

9.3 Regulatory environment

Forgoing the unpalatable possibility of economic meltdown, regulatory pressure will be the only direct way to modify transportation demand. At the present time there are no overt regulatory procedures that seek to cap or diminish any service demand within the air transport system. Provided progressive results are attained in terms of impact – through noise and gaseous emissions, etc. – the policy overall is to accept that there will be continuing expansion. 'Deregulatory' policies, shown to have encouraged market competition wherever they have been applied, seem set to be implemented widely, and will almost certainly encourage air travel. Challenging this trend will be seen to be an attempt by affluent nations, where 'market forces' have been unlocked, to curtail the economic development of nations with growing economic influence, and is unlikely to be tolerated.

Within bilateral agreements and more complex concords, such as the North Atlantic 'Open Skies' agreement, the desire is just the same as 'deregulation' – to encourage competition, to stimulate demand and thus to facilitate the increase in choice to consumers. With more choice, more options and a desire among the airlines to operate efficiently – implying that healthy load factors are maintained – the prognosis for growth remains in line with the manufacturer's predictions.

Capping demand by imposing capacity constraints is not unlike the trend towards congestion charging on roads in busy cities. While it seems commercially unacceptable to require airlines not to expand, the pressure is mounting on governments to slide a capacity noose around airports and airspace service provision. This is being achieved by refusing permission to expand airports (especially the number of runways), imposing capacity limits on facilities or modifying demand by using appropriate pricing policies – and adding taxes is a favoured way of exercising intervention. Given that the airports are, in increasing numbers of countries, private-owned entities, the justification for airport-based policies is at odds with

legislation that leaves airlines free to compete without constraint. Taxation is a governmental initiative that, on the experience of its use in retail markets, will dilute demand, but often only temporarily.

Capacity expansion can be affected, but not capped, by statutory powers exercised over safety regimes. The world is increasingly safety-conscious, and aviation has been at the hub of much pioneering safety work, so much so that operations have achieved a level of safety performance that has seen the number of accidents, in spite of annual movement rates increasing, steadily reduced over most years. The increasing complexity of aircraft is, occasionally, a cause for alarm, but mature safety-insight and appropriate remedial programmes have so far controlled some well-publicised ugly runs of events. As technology reaches into newer regimes, there will be an implied risk, which regulators will act to control. For example, large primary structures fabricated in newer materials, such as carbon fibre, will be designed, maintained and even disposed of in ways that are very different to those applied to metallic predecessors. A growing regime in which there is need for caution is in the use of software for safety-critical applications. The survivability of accidents has increased and the accident fatality rate is still an impressive safety record. Nevertheless, there are still catastrophic events that result in loss of life, and the investigations more than ever probe the behaviour of complex items that are expressed in lines of code rather than in physically identifiable entities.

Whether in the commercial or technical regime, regulatory policy has been to rein in the temptation to overregulate. The approach preferred in the technical regime is an example to consider overall. There is a willingness, in developments that have arisen over the last 35 years or so, to trust operators to identify and promulgate examples of best practice. In terms of assisting, through the appropriate monitoring of underlying trends that will point towards unhealthy outcomes, progress has been profoundly significant. For example, in respect of monitoring aircrew actions, the flight data recorder can yield information not just on profiles flown but also the efficacy of documentation and application discipline. Similar monitoring of ATC staff is possible in centres where advanced systems allow instant correlation of sensor data and the promulgation of decisions taken. Alternatively, the performance of mechanical and electronic items can be accessed in real-time as an aircraft is in flight, through 'health monitoring' of built-in test (BIT) system data. In these cases the data are sometimes buffered in electronic memory and sent to the ground on demand. On the basis of such data aircraft turnround activity might change accordingly or more long-term remedial maintenance action can be planned. These kinds of development have enabled a safety management system (SMS) culture to be imbued in operational organisations and have led to the diversion of technical and operational support staff from apron and hangar floor to office-bound

desks, where they conduct data analysis and reduction roles. Their decision-making role is perhaps more significant than ever, and will occasionally lead to operational procedure changes. The developments have been so progressively achieved that they have been integrated into working practices, and the cultural impact in technical regimes has been so gradual that its assimilation has been almost unnoticed outside the specialist areas involved.

Such rapid change has left a great challenge for teachers, whose temptation to imbue culture through skills has led them to consider how equivalently to equip individuals to respect what change they might have to expect in the future. If this has been a perennial dilemma for technical educators, the equivalent challenge in managerial sectors has been even worse. The solution will be found within approaches to the subjects that are not constrained by age-limited syllabi. Demands for viewpoints that balance a wider range of perspectives are not new, but they invariably prove elusive. By mapping the common ground that already exists and showing links through financial, regulatory, efficiency and service-quality channels in the major air-transport disciplines considered here, a contribution is attempted.

9.3.1 Multi-disciplinary perspectives

Regular publications – often constrained by their own specialist nature – rarely look at what is being done according to such wide viewpoints, so some leading examples are given below.

Airport safety

ICAO has encouraged airport regulators to impose an increase in the size of the runway end safety area (RESA), in which overrun or undershoot incidents can be contained. This has required addressing how the availability of space that can minimise the potential for catastrophic accidents can be created within the balance of the properties that stakeholders (airlines and airports) – who will be implementers and beneficiaries – will consider. It is recognised that the cost in some locations will be considerable, and it has been argued that in these cases a risk assessment will be allowed to outweigh overburdening legislation. A small airport that takes a new lease of life can expect to have to re-visit its arguments for less than the desired statutory RESA dimension in view of the way its financial and efficiency circumstances will have changed. The balance in this case is that so many more individual passengers will be put at greater risk that a vital service quality attribute must not be poorly moderated.

Aircrew safety

Within aircrew regimes the crew resource management (CRM) concept has been invaluable, over some two decades, in assisting management and operations to achieve a stable and satisfactory safety culture on the flight deck and increasingly also within those parts of the organisation that are directly integrated.

Equivalent resource application is encouraged by SMS processes that involve the operatives and management decision-makers throughout all safety-related disciplines. While not every circumstance can be 'regulated' either directly or through covert methods, aviation has set an enviable safety track record.

In fact, operational and technical legislative changes occurring across all sectors, including air traffic management (ATM), have been integrated within a property-led approach that has stemmed from increasing acknowledgement of the limitations of the historically evolved air transport operational scenario. The leading instigator has been ICAO, and a clear example of the way it can influence infrastructure development has been the Future Air Navigation Systems (FANS) committee.

Described in more detail in the previous chapter, the main point to bear in mind is that the FANS committee did not set out to define a solution or to implicate a technology or implementation. It was a multi-disciplinary and international body where the complications of integrating the old and the new were reviewed and ground rules drafted that would accommodate any solution that was able to display the appropriate properties. The view was that the implementations would have to be statutorily compliant, and thus the working groups within the committee were constrained by pre-existing safety legislation. This was never changed, but its implications were assessed and applications examined to the extent that the safety case content could be identified and enumerated.

Airspace safety

In many respects the FANS committee addressed a well-trodden path. Within the airspace community there was an equivalent conundrum in the early 1970s, when jet airliners were clogging the available capacity for aircraft operations over the North Atlantic. An ICAO committee was set up at that time to assess a North Atlantic Minimum Navigation Performance Specification (MNPS). This led to new legislation in the late 1970s.

Until around 1970 the acknowledged way of navigating the first-generation (narrow-body) jet airliners across the North Atlantic had been by using a hyperbolic area-navigation system called Loran. There were two Loran chains (sets of master and slave radio transmitters) on either side of

the North Atlantic, and their high-frequency (HF) radio signals presented a position report to the aircraft crew that was very accurate near the coastlines but increasingly less accurate as they flew towards the mid-Atlantic. Seasoned navigators could cope with the inaccuracies, and in many cases the airlines use pilots who were also trained as navigators, so they would periodically check their position on Loran. The flight engineer would control the fine-tuning of engine fuel settings and the three-man crew monitored their progress against fuel predications on what was called a ‘howgozit’ chart. There was a point of no return (PNR) that was the critical point from where, once passed, their least fuel to an aerodrome option was to press ahead. This was a practice that had stemmed from earlier generation piston-engine era operations. It worked well, although night-time crossings (the best-suited in scheduling terms for eastbound operations) often fell foul of a basic inadequacy of Loran. Its HF radio reception could fail to give an accurate position as the Heaviside layers from which radiation was reflected in the ionosphere would dissipate with solar excitation. To combat this, the crew had a device called a Doppler radar. This was a downward-looking radar that had a number of beams, in which the Doppler shift from ground returns could be analysed to determine the aircraft’s groundspeed and ground-based track (as distinct from the compass-measured heading).

A navigational-error audit of this navigational process was not flattering. The aircraft position was known to within about 20 nautical miles at the point where the crew might turn their attention to the Doppler radar. This error was time-dependent, and was about 5 nautical miles per hour on a jet airliner. After one hour relying on the radar the error could be up to 25 nautical miles, and after a further hour as much as 30 nautical miles. Therefore, even in the days when it was usual for jet airliners to ply trans-Atlantic, an aircraft could often deviate significantly off-track. As it came into range of the second Loran system, the aircraft would regain spatial position data and the error level diminished as the coastal fringes were reached. An early task for the ICAO had been to assess the probability of two aircraft on adjacent tracks wandering close enough together to represent an unacceptable risk, and the study (circa. 1950) had concluded that 120 nautical miles was the lowest acceptable separation.

In 1970 the Boeing 747 entered service and brought a new navigation system that had been trialled over the Pacific Ocean, called the inertial navigation system (INS). This is a military-derived technology, autonomous to the extent that it does not need radio guidance and has a time-dependent position-fixing error characteristic, which at the time of introduction was about 1 nautical mile per hour. The 747 and smaller aircraft that were INS-retrofitted were plying the North Atlantic by 1973 and track-keeping with an unprecedented accuracy. There were operational implications of having

widely spaced tracks, because only a few aircraft could get adequately close to the desirable jetstreams that would help propel them eastbound on night flights. Even in the afternoon westbound flights the sheer volume of aircraft wanting to fly the tracks available was approaching the capacity available.

The ICAO MNPS working group declared a volume of airspace in which it authorised a reduction in separation between parallel tracks, initially to 60 nautical miles and eventually to 30 nautical miles, on the basis of statistical studies showing that the probability of a hazardous navigational infringement was acceptable. The capacity problems were thus solved when MNPS was introduced in 1977, and the INS technology that spawned it was the key to the development. However, MNPS is exactly what its name implies – a performance specification – and as other navigation systems with equivalent ability to beat the minimum-required capability were introduced they too were approved for use in MNPS airspace.

It is to be noted, dryly, that this progressive change did not stifle one incredibly ignoble UK newspaper reporter stating that 'today flying the North Atlantic is less safe than it was yesterday'. Was he correct? Technically, yes. However, what such reporting masks is the fact that the acceptable level of safety had been upheld. It has been claimed that the probability of a mid-air collision by aircraft on parallel 30 nautical mile-spaced tracks nowadays equated to a catastrophic event about 1 time in 300 years.

More relevant to a progressive regulator perspective is whether there would have been other ways of solving the North Atlantic capacity crisis. One can muse on the fact that operations are intensely diurnal, and thus the tracks are overloaded for only part of the day. A potential solution could have been to redistribute demand throughout the fuller (24-hour) day. This would impact operating hours at airports, perhaps creating an unacceptable noise nuisance; it would possibly also ruin regular out-and-back aircraft schedules, resulting in utilisation reductions and forcing up aircraft operating costs. Alternatively, a price-charging scheme could be implemented, similar to modern city congestion charging. Try to fly the best route at the best time and you pay more.

These are not solutions that fall into the safety regulator's field of vision. The safety professional will say they never should. Had MNPS been evolved without the technology available to do it, at the time, would it have stimulated the development of appropriate technical solutions? Perhaps so.

These are indicative of the kind of thought that has to be applied to finding solutions in the more fertile ground of 'environmental' legislation. Some modern commentators would call it 'out-of-the-box' thinking and others would categorise it as 'joined-up' thinking. No matter which side of the argument holds sway, the opportunity for innovative solution recognition is as great as ever.

9.4 Operational environment

Nowadays, worldwide, the airspace businesses must be FANS-compliant. That does not force them to change, as FANS has not created a prescriptive 'must do'. It has put in place processes that enable existing minimum-requirement systems (right back to procedural) to be integrated with more modern systems. FANS should ensure that development will proceed in such a way that global compatibility is maintained, but the situation for an operation that spans several airspace provider areas is that the performance in the weakest link in the chain is likely to set the most constraints on the operation. This will not be true if that section of airspace is so sparsely populated that a non-optimal clearance will be a rare necessity. This allows countries with little domestic air travel demand and virtually no overflying traffic (a good example would be Nepal) to minimise their airspace service provision (ASP) investment. A country with little domestic traffic but a lot of overflying traffic will find that it is more under pressure to invest to preserve service quality for overflying traffic. In the spirit of multi-disciplinary thinking, such an ASP can charge for its services, showing that it does have a justification mechanism.

A very different topic, but perhaps most overriding of all, is aviation security. A few decades ago, security was applied piecemeal and on demand, it was strict in some places and almost non-existent in others. Nowadays an ICAO Annex is devoted to the topic, and airports in particular are tasked to take on the front-line role in combating the threat of terrorism. All aircraft operators and – in principle – all airports with cross-border (international) services have to implement stringent security measures. Aircraft operators have to perform due diligence in respect of vetting and approving staff, planning operations that are non-contentious and operating in accordance with regimes they encounter and whose demands are often onerous. In all this hubris, the service-quality aspect is a major dominating factor, as any security procedure is always likely to be judged as having a negative impact. Thus it has to be sold on the basis of its overall efficiency. Without it, the air transport system would be worse overall.

9.5 Environmental accountability

This is a theme that has had few visible facets, apart from noise and air/ground pollution constraints, but that is likely to be a seed that will spawn governmental disincentives: taxes, quotas, etc., that will attempt to curb air transport growth. Environmental accountability will be a battleground for managers in the future.

One widely expected transformation is legislation that will 'reward' (through carbon-credits in contemporary parlance, but this could change as

attitudes gel) and thus influence choice. Such legislation will be challenged, and not just by air transport specialists. Do people have the freedom of choice or will they be forced to limit their choice/usage? The anticipated trend is to force short-haul travellers to use surface transport more than air transport. A high-speed rail link between two busy commercial centres can be shown to have capacity and operational cost benefits that an air service finds hard to challenge, but the air traveller is often not flying to attain the same point-to-point service as the rail traveller, as the attraction of a service to a busy international airport will often be that they can transfer from an incoming to an outgoing flight. Travellers originating or heading to or from a province that does not have a direct international air service, or even fast surface transport links, can find legislation that will limit their choice detrimental to the province's economic development. That in turn influences economic policies, and it can impact demographic development, so that curing the economic effect becomes the cause of economic change, and the attributes of the legislation, in terms of impact according to the properties that the public perceive, can be more negative than positive.

This is a political and economic battleground, as demand is fuelled by prosperity. If regions are less or better favoured in economic terms by the shape of legislation that is designed to allay environmental impact fears, they will react accordingly.

The traditional starting point in the field is the environmental impact statement (EIS). This considers what impact aviation has on Earth sciences. It is concerned solely with the direct, and indirect, impact, and an EIS can refer to any business: aviation is just one. The term used stressed that it is a study of 'impact': it concentrates on the effects of energy usage. In aviation, the use of fuel-burning vehicles that emit their exhausts directly into the atmosphere creates most scorn. Previously (Chapter 5) it has been shown that aircraft fuel use per seat, per unit distance, is very similar to motor vehicles. It can be argued to be less, given the low occupancy rate of motor vehicle seats. With 25 000 or so aircraft in service, offering 130 seats (a rounded average of world fleet capacities) and each flying between 2 and 4.5 million km per year (compared to about 15 000 km annually for a typical four-seat passenger/driver road vehicle in Europe), the world aircraft fleet provides a service and uses fuel at the same rate as about 150 million family cars or about 15 million lorries. These are not trivial numbers, but they are much smaller than the world fleet of cars, lorries and other road-using vehicles.

Aviation air pollution tends to be concentrated in the lower atmosphere mainly in the vicinity of airports. Engine manufacturers have to monitor and meet 'clean air' regulations (acknowledging that no emission is ever 'clean') just to certify their engines for service. They achieve remarkable levels of performance with no catalytic convertors or other devices that trap

pollutants. They make the engine run as efficiently as possible, and emit the clearest possible air. The legislation of noxious gas emissions will no doubt continue and the targets will fall, but there are limits to what can be achieved. What modern jet-engine manufacturers have achieved is worthy of great respect. Airports encourage the use of ground-supplied energy, rather than the running of noisy, as well as inefficient, auxiliary power units (APUs) on the aircraft. Start-up (which can be an unavoidable period of low engine efficiency, with consequential pollution effects) and taxiing, when the aircraft engine settings are low, can emit relatively large amounts of air pollutants. Even so, when not just cars but also public-transport vehicles that convey passengers to/from the airport are taken into account, as well as the car usage of staff and the vast quantities of lorries, vans, baggage-handling tractors, aircraft tugs, etc., that are needed to support apron and terminal operations, the emissions from all of these is often as significant as that from the air vehicles. The managers who try this as an excuse to justify their own product may do so unwisely, as the services offered at the airport generate the activities described and as such they are attributable in principle to civil aviation.

Once aircraft are cruising they reach the target efficiency points used in the engine design process and the emissions are remarkably low. A modern 300-tonne airliner with a cruise lift-to-drag ratio of 20 (some are better) generates only 15 tonnes of drag (needing around 150 kN of thrust) and the fuel usage can be less than 9 tonnes per hour. This can be a 350-seat aircraft that cruises at just below 1000 km/h, which means that it is emitting gases in which around 2.5 kg of fuel have been burned each second. That is about 9 kg per km, which is not bad for a vehicle that carries the equivalent of almost 90 cars and is travelling at close to the speed of sound. However, looking at the situation from a global perspective, the whole population of aircraft is probably emitting 25–30 tonnes per second worldwide or almost 90 million tonnes per year.

Not all of the fuel ends up as noxious gases, and most of it is readily absorbed in organic cycles. Some is not, however, and the gases, because they enter the atmosphere at high altitude, can have other side-effects. There is a strong belief, with evidence mounting, that the skies are less bright because of gaseous particle dispersion in the stratosphere. Once aircraft stop flying, the particles disperse rapidly. One of the best circumstantial pointers to this effect came from research in the USA in the wake of the 9/11 disaster in 2001, when aircraft were not flown over the US continent for several days and the sky brightness was brighter than at any other time in the year. There was also a favourable weather system, so such research needs to be carried through more conclusively.

More perplexing in some respects is the tendency for aircraft at high altitudes to leave a condensation trail, or contrail. It will form only if there is

sufficient moisture in the atmosphere and so cannot be guaranteed. There are some days when invisible crystalline water will not just condense in the heat of the engine exhaust but will be wind dispersed, and will trigger other water crystals to bind to those already rendered visible. In busy airspace regions 'mare's tail'-style cirrus clouds can form. It has been estimated that 1% of the world's surface is covered by such cloud at any point in time. There is a fear that this figure will rise to 2% by 2020. There is no direct evidence that this does any harm, but it is a significant redistribution of reflective material in the upper atmosphere and should cause concern.

Aviation businesses that are under unremitting scrutiny for environmental misdemeanours have begun to respond to the questions, with airlines appointing environmental executives from as long ago as 1990. Several manufacturers and some of the larger airports have joined their ranks, but there is little evidence that airspace service providers are likely to follow suit, largely because they are capacity-strapped and cannot be seen to be operating so far below peak efficiency as they possibly would with environmental palliatives to contrailing in place, etc. They will almost certainly have to bite this bullet one day soon, believing that a 2% saving in cruise time will equate to some 2 million less tonnes of fuel-burn annually. Meanwhile, aero-engine manufacturers can strive to find a long-term technical solution and airspace providers can try to organise 'direct routeing'.

Boeing has led the cry to address this situation in context with several other issues, and proposes more smaller, longer-range, aircraft, believing that this will allow more point-to-point services. This is a solution alluded to in the first chapter and examined in more detail later. The fact that it is a viewpoint that lends itself to offering such a wide range of benefits serves as an excellent reminder that a 'systemic' view can often prove to have hidden benefits.

These examples serve to remind managers that they must broaden the debate from its current rather furrowed line of investigation. The desire must be to broaden, rather than to prevent, the existing debate by seeking acknowledgement that there are many additional balances to strike, all equally as environmentally sensitive.

Direct intervention in business is not being considered, but the political imposition of constraints is, and justification is all too often derived solely from the EIS. Constraint leads to system performance imbalances (for example in capacity, demand and delay relationships), which will impact viability, efficiency and effective criteria within the businesses involved. The drastic scaling-down of whole supply industries can certainly be shown to achieve the desired environmental impact reduction, but demanding the recognition of unreasonable compliance requirements will lead to changes in work patterns. These will affect GDPs, lead to population redistribution

and could even destabilise the economic platforms on which some societies depend. Attempts to protect society legislatively from the environmental impact of civil aviation with such weak initiatives as taxation will increasingly open the possibilities of secondary impacts on society.

If the simplest possible solution is attempted – seeing that air transport capacity is capped – the outcome will be to deny, or divert, demand away from nations where environmentalist policy is strongest. This simple solution becomes the easy political option when time limits are introduced, with the excuse that they are a damage-limitation factor. Rather than steering towards attainment, the political will is to cower and pretend appeasement, but this can have a profound impact on national ambitions, which in turn might be limited by a self-imposed energy crisis. Facilitators in such debate find this is a classic 'double-edged sword' situation.

In respect of the technical possibilities, the air transport business will produce more 'environmentally friendly' aircraft (these will be probed in the next chapter), there will be more efficient operations, as the subsequent chapters on airline, airport and airspace development issues will chart, and there will be service quality developments that will reflect public perceptions and concerns. The environmental impact will therefore be moderated, thanks to wider public debate, but it is inevitable, if current demand trends do not moderate, that the average travel demand per human will increase.

Across all modes of transport the call for less travel demand will always be a difficult hill to climb. People have become used to demanding the right to travel. In the well-developed nations there is an, as yet, undiminishing requirement for travel per head of populations as a whole. In lesser developed, but economically successful, nations, travel demand is rising fastest of all. They do not expect to have constraints imposed on them that were not imposed on the better-off nations. The debate can move full-circle very quickly, because they will see the imposition of constraints as unfair. An inevitable result will be that travel demand will be reduced either through legislative powers (that governments are unwilling to apply) or through societal developments (that perhaps are implanted by legislative procedures). The civil aviation business must come to the assistance of legislators and provide clear guidance on the qualities that are needed of future impositions. In addition, it must show a willingness to help reduce the societal impact of its own operations.

Some of these changes are unquantifiable and their impact can therefore be assessed only in terms of likely outcomes. The way that these changes are brought together will almost certainly be influenced by the perspectives gained from data derived from the monitoring of properties of the system, and at the present time these are not well defined. By reviewing the understanding that has been developed in studying the elements of the air transport system, there are some clues as to how future perspectives can be

shaped. The environmental impact of aviation, in respect of its interaction with Earth sciences, is undoubtedly one of the most difficult conundrums to address at the current time. There is an immediate need for positive responses to be made, more often and more publicly, than is tending to happen.

9.6 Effects on the business

In terms of noise and air/ground pollution, air transport businesses have done enough to set performance attributes to mean that, if regulation was benchmarked to 40 years ago, aviation would stand very proud. It uses less fuel per passenger-kilometre than ever before, it has quieter aircraft, it has extensive ground pollution safeguards in place and it employs monitoring techniques that are sufficient at least, at this stage, to provide the information that demonstrates and ensures its sound performance.

The corollary is that the same data provide evidence of the impact of activity, leaving civil aviation in a defensive position. Can all elements of the business be encouraged to join forces to ensure that reasonable restraint is sought and applied? Possibly so, but it will require governmental intervention, and that will be difficult if such blunt instruments as taxation are overused. This is an international-level topic to which the air transport business is a hostage, and it must use what leverage it has to be an influencer. It is not easy for any civil aviation CEO to balance environmental demands with demands for increasing productivity. The requirement to be proactive in what is a diffuse and often openly hostile area of activity is one of the greater challenges of the era. It seems inevitable that recognising what is desirable and what it is that it is necessary to address, in addition to the functions that are classified as essential, will become regular points of concern. If businesses fall into feeling that they have to be efficient and profitable overall, they lose sight of their effectiveness targets, and can find that they are bound about with statutory compliances that are blunt at best and useless at worst.

The sheer quantity of debate that is necessary can be difficult to manage. The remaining chapters address change from the perspectives of the four system elements highlighted here. In a bid to capture the majority of the issues while providing some structure to debate outcomes, five possible scenarios are examined in the final chapter. It is acknowledged that these are likely but not inevitable situations and that, while each will be referred to in isolation, there is always the possibility that more than one (as one example so far has shown), and perhaps even all of them, will have a future impact on the air transport system.

10
Coping with change: the manufacturer's challenge

Abstract: This chapter reviews trends that in the past characterised change in aircraft manufacture, and considers newer developments. The way these will impinge on aircraft characteristics are analysed under viability, compliancy, efficiency and effectiveness headings. The implications of requirements that can be perceived to be imposed by other elements within the air transport system are considered, and the ability of the manufacturer to respond to change from these sources is postulated.

Key words: financial viability, statutory compliance, technical efficiency, effectiveness.

10.1 Introduction

The two major manufacturing challenges for airliner developers include making aircraft more environmentally acceptable – they will be hard-pressed to have any design dubbed environmentally 'friendly' – and retaining sufficient market share of annual production to be a viable producer. Their customers, most notably the airlines, expect their products to be market-leaders in terms of seat operating cost, but will pay attention to attributes such as flexibility (in terms of payload–range combinations over which acceptable economic performance is achievable) and there will be a few niche attributes, like short field performance, that will be important for some specific operators. Aircraft will need to be compliant with safety regulations (well defined, but being expanded as technologies such as advanced avionics and new materials make their way into airframes and engines) and noise and emission regulations, which change year by year. These are proactive regulations, changed sufficiently to reward and spread the application of best-practice and drawing close behind the technology limits set by patent and intellectual property rights.

A few initiatives are possible that will blur the edges, and especially of

operating costs. Nowadays aircraft have a list price and the occasional buyer might sign a contract at that value. It is more likely they will sign a deal that includes support elements, to include on-going engine, and even airframe, maintenance charges based on predefined utilisation levels. Buyers will often choose to finance the deal, whether it is a purchase or a lease, through financial institutions. In the case of leasing, an aircraft can be acquired through an aircraft leasing specialist, without reference to the aircraft company. Just a few customers pay in cash, and they usually do so only when there is a healthy discount incentive.

10.2 Financial viability

There has been a steady demand for new aircraft over recent decades, equivalent to about 1000 per year. The annual average production level has tended to grow, and the forecasts suggest this trend will continue in order to serve the anticipated increase in demand for air transport services. Both Airbus and Boeing suggest that they and other businesses will build around 1300 aircraft per year in the 20 years up to 2025. Their forecasts will be analysed in more depth later in this chapter.

The demand in earlier times was met by a large range of manufacturers. They would design and build aircraft in batches, almost like bespoke orders, but it was those that adopted a less customised strategy that have proved to be the more successful suppliers in the fullness of time. By planning production at a steady rate and offering a product that is flexible in terms of performance and internal configuration, users are offered a tailor-made product, but are also aware that their aircraft has a lot of commonality with other users' aircraft. This simplifies and makes more economic the supply chain and operational support infrastructure associated with each type of aircraft.

A particular success was the Boeing 727. It was the first civil airliner to pass the 1000 production unit milestone, and almost 2000 were built over about 25 years. At the peak of its success in the 1970s, 12 or more Boeing 727s rolled off the Renton production line every month. In financial terms Boeing demonstrated that manufacturing needs a product that can sustain long-term production, so that the investment on the design and development phases can be recouped against the vast cash-flow deficit that faces the builder and its suppliers as the aircraft establishes itself in service. As well as income from sales, there is considerable long-term revenue to recoup from aircraft support. In a 20–30-year operational life the cost of aircraft maintenance, roughly spoken of as 15% of annual airline operating cost, over the full operating life (20–25 years) of an airframe will be equivalent to 3 or 4 years' operating revenue. With hundreds or even thousands of aircraft in service, and only the original suppliers of airframe, engine and system

components able to source the items needed to support in-service operations, a successful aircraft programme is a cash-cow, milkable for up to 40 years after the design has been launched as a project.

The way that manufacturing has coalesced into a few companies is all down to viability. The USA is a vast market for airliners, but even Boeing's biggest rival, Douglas, struggled to maintain a viable financial bottom line and in the 1970s they merged with McDonnell. Several firms left the scene, including Convair, and even Lockheed struggled to make money from the L-1011 TriStar, so that, while they remained in the military sector, they withdrew completely from airliner production.

Throughout the world, similar tales were apparent in other countries. In Britain the firms of old – Avro, Bristol, de Havilland, Vickers and many more – had merged, under government pressure, in the 1960s to form the British Aircraft Corporation (BAC) and Hawker Siddeley Aviation (HSA). This did not lead to financial success and the firms merged, initially as a public corporation but eventually privatised, as British Aerospace (BAe). In financial terms, there were no successful British jet programmes, save the BAC One-Eleven, which only sold in hundreds over a production that spanned almost two decades. There was the Anglo-French Concorde project, but that was a one-off project, technologically pre-eminent but not a financially, or environmentally, acceptable product for the era.

In the Soviet Union the market was more regulated, and Antonov, Ilyushin, Tupolev and Yakolev were all significant civil aircraft builders. In every case the firms tended, under the auspices of government control, to be too willing to meet customer demands for customisation to create truly viable products. Their sales rates were low and when they were at last, in the late-1980s, able to open their doors to world markets, it was difficult for Soviet firms to provide the evidence that Western regulators require from continuous scrutiny about the quality of suppliers and subcontractors, although Yakolev and Tupolev tried especially hard to leap this hurdle. In financial terms, most European airliner manufacturers lacked adequate market penetration to create a programme that was financially viable, and the Soviet firms had to be content to provide aircraft that were important parts of the social and economic model of the more totalitarian state in which they were based.

Financial credibility was the spur to the formation in the late 1960s of a European consortium, Airbus Industrie, headquartered at Toulouse in France. The firm loosely inherited the original Sud Aviation team in France, which itself had been the product of an earlier attempt to rationalise French aircraft manufacture and other aircraft companies in Europe. It was a bold and successful attempt to rescue what was technically credible from the commercial wreckage of the Concorde project, and while Concorde is hardly mentioned as an Airbus legacy, it was the platform from which collaborative

efforts were able to create a viably scaled European design and production initiative. There is considerable international concern that Airbus is still a financial asset of European governments – especially France and Germany – although it is a financially accountable industrial group. EU regulators are often under attack for not clarifying these concerns, but meanwhile Airbus has become one of the two leading civil aircraft manufacturers worldwide. Boeing, who subsequently absorbed the McDonnell–Douglas enterprise, is the other civil aviation giant.

There were significant attempts by other companies to carve niches, such as Fokker in the Netherlands, but eventually the financial institutions were reluctant to support their projects and they fell. Sheer national determination in Brazil and some national pride and commercial courage in Canada have seen two newcomers, respectively Embrear and Bombardier, rise from bit players to significant suppliers in the last 30 years. Bombardier in Canada, through acquisition, obtained two mature products, the de Havilland Canada Dash-8 turboprop and the Canadair Challenger business jet (and they have absorbed the former US Learjet enterprise). They successfully refinanced their civil aircraft programmes and have become a leading 'regional jet' (below 100-seat capacity) airliner manufacturer. Embrear has been catapulted through a staged programme, starting with the 18-seat unpressurised Bandierante airliner in the mid-1970s, to the point where they now have a family of 35–120-seat regional jet airliners. Apart from a further European consortium, ATR, with 50- and 70-seat turboprop products, Bombardier and Embrear reign supreme in the small airliner (turboprop and jet) regime.

It is not impossible that a new Western airliner manufacturer will emerge, but if it does, it will have to be virtually self-financed, and the cash-flow that will have to be handled implies that it will be a subsidiary of an existing industrial enterprise. No likely taker of such commercial risk is apparent. More likely is that the political will in an emerging economic power (China and India being the prime candidates) will support a new enterprise. Japan keeps surprising the world with new products, often with clear civilian applications, but built to supply small numbers to their own military surveillance, training and freighter operations. They tend to steer clear of full involvement, but have been a significant airframe component supplier to the USA for many years. Meanwhile, Boeing and Airbus have begun to lift the lid on long-running discussions to commence assembly, and even production, in China.

The airframe-firm suppliers are smaller, but are no less important parts of the fabric of the manufacturing industry, but they are also fewer in number than they were in the past. For example, there are only three leading aero-engine companies – Pratt and Whitney and General Electric in the USA and Rolls-Royce in Britain. They collaborate with many other firms, so while the

10.1 The Boeing 307 Stratoliner, in the 1940s, was well-equipped in its day and had four seats on the flight deck to accommodate pilots, navigator and engineer. Compare this flight-deck with the Boeing 787 Dreamliner (Fig. 10.2) to appreciate how much the technology in airlines has changed over the 60 years.

greater proportion of sales is through these three firms, there are some companies, in France, Germany and Canada for example, that supply components, and indeed contribute to development and research expertise, and are still sizeable manufacturing firms in their own right. A similar state of affairs exists in the aircraft systems market, with the existing front-running firms having aggregated expertise through acquisitions.

The financial barriers that bar entry for newcomers in these sectors are as sizeable as those facing the airframe business sector. They are surmountable, once again, only if newcomers are given considerable financial support, either from national governments or through industrial diversification. In most European countries, with the exception of France, there is virtually no significant contributor to civil aviation systems expertise. The remaining firms are specialists in sensor technologies or systems research, or are production outposts of the US firms that have acquired them.

Figures 10.1 and 10.2 illustrate the changes that have occurred within the airliner flight deck.

10.2 The Boeing 787 Dreamliner will enter service in 2010 and is the latest modern airliner with a two-place flight deck. It will be the first type to introduce the head-up display (HUD) as a fundamental piece of airliner display equipment.

10.3 Statutory compliance

Economic statutory controls on airlines might seem irrelevant to manufacturer-based debate, but their impact can be profound. The kind of impact they do have is that as bilateral treaties open and occasionally close new market opportunities, so aircraft manufacturers will parachute in marketing teams. They are backed with supporting data from route analysts and financial market specialists to offer what they perceive to be relevant products and to give guidance on how they can be financed and markets generated. This can even result in financial incentives from a builder, in which case the move will almost certainly have been approved in government offices that regulate overseas trade and investment.

Technical statutory compliance of an aircraft is an essential attribute, and once 'approvals' have been granted, through principally the Federal Aviation Administration (FAA) in the USA or under the Joint Aircraft Authority (JAA) in Europe, the manufacturers will maintain an acceptable record of compliance. In most other countries throughout the world these two regulatory sources are applied by proxy, or ICAO Annexes (principally 6, 7 and 8) are used.

The structure of compliances has not changed for many decades and does

not seem likely to need to be changed. There are design, manufacture, training and overhaul approvals, to name the main categories only. The procedure is to ensure compliance in the areas of relevance only, so a manufacturer of electronic systems will have quite different compliancy requirements to a supplier of airframe parts. In their compliancy procedures there will be elements of the processes already outlined in Chapter 4, which determine how safety issues are addressed. For many decades there has been no change in the way that acceptable failure cases are expressed, and change is difficult to apply without dispensation for inherited compliances. However, there are always new avenues that need to be explored.

A significant case study in the 1950s was the in-service structural failure of the Comet airliner because of metal fatigue. Some years later, and equally catastrophic, was the aero-elastic failure of the Electra turboprop aircraft wing. These were design case failures that slipped through unnoticed because of the pace of technological change.

In the current era an equivalent risk source is the use of carbon fibre in primary aircraft structures. The certification authorities have supported the deep technical evaluation of failure cases in different applications, to ensure that essential design attributes are recognised and legislated appropriately in design requirements. They have simultaneously encouraged the introduction of the new material in secondary structure applications so that several decades of in-service experience has been accumulated and appropriate maintenance legislation drafted. The ability to move ahead with new technologies is sometimes profoundly linked to other emerging technologies. A simple, but very effective, example was the recognition that multi-layered carbon fibre could 'delaminate' with age, but that checking for this failure mode traditionally required invasive or time-consuming testing processes. The solution that an aircraft engineer proposed, and that led to new techniques being adopted, was to use a thermal imaging camera to scan external carbon fibre items as an aircraft taxied in after a flight, in which case any delaminated skins would reveal regions of unmelted ice.

As these words are written the first airliners with significant parts of the primary structure manufactured in carbon fibre are entering airline service. They represent a large departure from previous practice. They have been preceded into service by large numbers of military aircraft with equivalent structural applications, and that itself shows conservatism. However, airliners accumulate flying hours at a much greater rate than military aircraft, so the programmes that have been used to identify age-related structural item problems will ensure that appropriate monitoring and testing of the new aircraft's most critical components are among the most rigorous in the history of the business. Only when there is sufficient statistical evidence to support the relaxation of such confidence-building programmes

will the risk associated with these new materials be accepted without such oversight.

In operational terms, the extended-twin operations (ETOPS) procedure, which lifted the virtual ban on twin-engine airliners being allowed to fly over areas where there were few diversion options, was a design initiative of the 1990s. The aero-engine manufacturers teamed with the airframe builders and certified the airframe/engine combination with an initial operating licence that would allow operations to a specified range (expressed as time) from declared diversion bases on particular routes. The initial clearance was 90 minutes, so on North Atlantic services this meant that a USA–UK flight had to head north of the optimum track, keeping within 90 minutes flying time of bases in Canada, Greenland and Iceland. As engine reliability data were accumulated, the ETOPS certification process allowed operations to be conducted with 120-minute, and then greater, diversion time limits. The ultimate aim is a 210- or 240-minute clearance, which is achieved with particular models of Boeing 767 and 777, and Airbus 330; this allows almost unhindered direct routeing almost anywhere in the world. This is an example of a flexible statutory policy as the engine reliability data are continually scrutinised. An aircraft type, and even a particular airline, can have their diversion time limit reduced with immediate effect and applicable indefinitely, or certainly until the time that they can furnish evidence of a return to acceptable performance levels, if its data show evidence of engine reliability that will breach the risk criteria in their existing ETOPS clearance.

Nowadays safety regulation improvements are less fundamental and more operationally related, like the ETOPS example. Examples will be delved into more deeply when procedures affecting airlines and airspace providers are explored.

10.4 Efficiency

An efficient aircraft, viewed technologically, will have aerodynamics, structures, engines and embedded equipment systems that provide the possibility of superlative performance. That will be reflected in operating costs, and it is rare to find any product in a competitive market that will excel on all fronts. If there was a ‘consumer survey’ of airliners it would be sensible to compile it under the technical headings quoted above.

10.4.1 Aerodynamics

Aerodynamic research within the civil aviation sector, in that it recognizes the limitations imposed by physics and it steers clear of confronting the public wrath that will come from exploiting supersonic flight regimes, is nowadays exploring areas that are less extensive than those considered in the

latter part of the 20th century. There is still a lot to do, however, and the relationship between effort and attainment means that progress has slowed and is increasingly expensive. Two avenues seem to define what will be explored.

The majority of aerodynamic research effort is devoted to achieving small incremental evolution. There are many discrete areas of development, from the shape of the fuselage nose, the contouring of its aft section, the sculpturing of wing–fuselage junction fairings, and so on. Because it is the attainment of a good cruise lift-to-drag ratio that determines the most important fuel efficiency, the design of the wing is still a clear priority for designers. The surest way of minimising cruise drag is to develop a wing that combines a tailored aerofoil (wing cross-section), with a slender (high aspect ratio) plan. The more slender the wing, given it is a structural item that is cantilevered from the fuselage, the more it will bend upwards towards the tip and potentially the more limitations will be imposed on speed capability by aerodynamic and structural interaction (aero-elastic) effects. Unless normal cruising speed and altitude change it is unlikely that more slender wings will be developed in coming years, but they will be as highly swept back as possible and the proportion of aircraft using slender wings and elegant 'winglets' seems inevitably to increase.

Changing cruise speed and altitude is not out of the question. Current designs have gravitated towards jet-powered designs that cruise between approximately Mach 0.75 and 0.85, with the lower cruise speed attributable to the shorter range aircraft and a lower speed range, between approximately Mach 0.5 and 0.65, for turboprop airliners. Concorde set out to burst into Mach 2.0+ and carried noise and fuel-efficiency penalties that mitigated against its widespread usage. Boeing expressed an interest in a high subsonic cruise design, the Sonic Cruiser concept (see Fig. 10.3), around 2000–2001, but this was only about 10% faster than current jet designs and the time benefit was so small on most operations that it was not favoured by airlines. To go faster is to enter into the supersonic regime, where sonic boom and higher drag, and thus lower fuel efficiency, are factors that hamper economic performance. Some small business jet design teams eye this regime, but airliner design teams seem certain to be wary until the business-jet community, if ever, demonstrates a viable solution.

Environmental concerns, as has been intimated in the previous chapter, could spur interests in lower altitude cruise conditions. This would probably equate with lower speeds, which would be an unfavourable development from a passenger's view (on long-haul-operations). One greater side effect would be the likelihood of creating a legion of airspace capacity problems, so at this stage, provided traditional cruise speed and altitude combinations can be justified, they are unlikely to be affected.

The lesser funded, but more exciting, avenue of aerodynamic research is

10.3 Boeing challenged the 'conventional aircraft' concept when the Sonic Cruiser project was revealed in 2000. It proposed a radical change of aircraft shape, and promised about 10% more speed than other airliners. It was the customers that decided this was too radical a design to order and caused the programme to be halted.

that devoted to more radical aerodynamic solutions. Concorde has been a stark warning that there is a need to tread carefully, but interest in the potential of more radical aircraft configurations has been re-ignited by the success (in operational terms) of the latest generation of military aircraft with advanced 'stealth' technology. If they can make odd-shaped aircraft fly, and work for them, then why not the airliner community? This has not prevented research being sanctioned and conducted into advanced blended-wing body (BWB) aircraft, using scaled-down and unmanned research vehicles.

The BWB concept is not just about aerodynamics, although the potential increase in the lift-to-drag ratio offered by the sleek configuration is the main attraction. It also requires extensive use of newer materials, and with the widespread acceptance of man-made materials (all forms of composite plastics and fibres) in place of natural metallic materials already under way (more about this in the next section), metallic-based industries that will not cede to change may be under threat anyway. Additionally, and again building upon a trend that has already been partially exploited, the BWB

will be a fly-by-wire (FBW) aircraft. This implies full-FBW capability, and frees the designer from considering only those aircraft shapes that assure stable flight when all the systems have failed. This will be startling new ground for civil aviation, but the way has been paved by partial-FBW (still stable airframes but with electronic controls) in the 1990s generation of aircraft, such as the Airbus A330/340, the newer A380 and the Boeing 777 and 787.

10.4.2 Structures

Plastic-based aircraft were mooted, and simple designs flown, in the late 1940s, and by the 1960s the glass fibre sailplane was a common sight in the competitive regime. Nowadays the glass fibre light aircraft is well established, and for over 20 years there have been kit-build aircraft based on the material. It tends to use glass strands, directionally laid or woven, within a plastic matrix. It can produce a blemish-free finish that is better aerodynamically than a skin that has rivets, no matter how expertly they are flush-finished. Additionally, a major aircraft item – a fuselage or a wing – is now a handful of components, glued and screwed, rather than a mass of smaller items all assembled with tremendous effort. The cost of production is much reduced.

Carbon fibre filaments were discovered in the 1960s, and in terms of their tensile strength they are stronger than almost all known metals. A natural development was to replace glass fibre with carbon fibre; carbon fibre reinforced plastic (CFRP) was first introduced in the late 1960s. Within a few years small items were test flown, and then with proof of concept in smaller aircraft, the time came to commit to larger components and operational use in front-line military aircraft, and then (around the 1980s) to civil airliners. Compared with aluminium alloy, CFRP is lighter, as well as cheaper to build. However, it is not able to be modified: once the item is set, the item stays that way. To its credit, it does not suffer fatigue as seriously as metal (the belief is that to all intents it is a fatigue-resistant structure, but ageing does set limits – they have just not been reached yet). It can be damaged and it can be repaired, but spotting damage and effecting repairs have been the stuff of research programmes. The broad thinking that has spawned some solutions has already been alluded to.

Suppliers that are wedded to metal will lose out in terms of building major structural items for aircraft companies, but they will compete to devise manufacturing processes that will improve the efficiency of smaller items. Brackets that were once simple strips of metal can be forged or moulded, and even eliminated, by new computer-aided manufacturing (CAM) processes that allow hitherto impossible shapes to be created and

manufacturing to be achieved to minute tolerances, with less skilled labour and less time required overall.

This is a necessarily brief description of the developments in this area, but sufficient in this case to show that there are clear benefits, in financial and efficiency terms, to make the investment in such technology worthwhile.

10.4.3 Propulsion and other systems

It is often quoted that over 25% (some say as high as 40%) of the value of the airliner that rolls off a production line is attributable to engine and systems suppliers. They are introducing change in many subtle ways and could be the trump card holders for the most beneficial future technologies.

Aero-engine industry design teams, like those in the airframe business, refine the aerodynamic and structural design of their products through equivalent technical research. The design of turbo-machinery (the fan, compressor and turbine) is specialist aerodynamic work, with material and fabrication technology greatly influencing the scope for solutions. There is hardly a year passes without some significant development in these areas, and in that regard aero-engine design and manufacture is still a fertile technology-led field of endeavour.

The environmental impact of jet aircraft is almost all down to the efficiency of the engines, and the high bypass ratio turbofan engine has been the engine of choice for some 40 years. Over that time the amount of air that is handled by the fan and that bypasses the engine core has increased substantially. If it is increased even more, the point will be reached where there is no longer a significant benefit in having the fan section within a circular cowl. The so-called ‘open rotor’ jet engine concept is not far removed from the simpler (or so perceived) turboprop engine. There are several key technologies that determine what is achievable at any point in time, but the most influential of all is material technology. The higher the temperature that can be achieved in the combustion process within the engine, the more energy can be extracted. However, that means running the turbine blades at temperatures above those at which metals will melt, so the blades are fabricated with internal labyrinths that are cast or exposed with laser etching. Ensuring not just the efficiency but also the effectiveness of an engine requires due consideration of the way the blade condition is monitored in service, and thus the engine maintenance process becomes a part of the operational burden and affects ownership costs. Get it wrong and frequent engine failures can be more than an embarrassment, in that safety certificates will be suspended until due diligence is proven.

The aero-engine companies increasingly employ electronics to balance and optimise the characteristics of components and to fulfil the essential monitoring wherever possible, in what is an increasingly complex product.

In some of these cases the optimisation is to forego the best possible design-point efficiency for better overall life, and thus benefits that can be sold in terms of improved lifecycle (nowadays 'through-lifecycle') costs. Most high-performance engines nowadays use a full authority digital engine control (FADEC) system that will interpret control inputs and off-take conditions, and redistribute any internal engine settings to maintain the best possible overall engine performance.

The above example is just one of the many avionics systems that have been evolving rapidly in recent years. Sensors that are physically less obtrusive or printed circuit boards that are stiff enough not to deflect unacceptably under loads are examples of projects where development often goes unnoticed.

The Airbus A320 and A330/340 family and the Boeing 777 introduced fly-by-wire (FBW) systems. Whereas hitherto types had a direct link from the control column and pedals to the aircraft control surfaces, these aircraft used electronic connections. Boeing has kept to conventional stick/pedal controls, but Airbus has adopted a sidestick, while retaining pedals. Both design teams have used the electronic link to introduce a subtle, but vital, safety feature that only comes with FBW. This is flight-envelope protection. For the first time, the aircraft will not necessarily do what the handling pilot requests. Instead, the system looks at the aircraft's limitations (these change as the aircraft mass or speed and altitude are varied) and will prevent the crew manoeuvring into a potentially dangerous flight regime. Its development has been at times traumatic, for like a good air-conditioning system, if it is working as planned, its presence will hardly be noticeable, but if it does not work as planned it will no longer be trusted. The acceptance of FBW in airliners was a significant development, with aircrew almost unanimously favouring it over a more conventional system. Its presence has also allowed the aerodynamic contribution to stability to be reduced. The tail surfaces on a FBW airliner can be made smaller, thus reducing drag, or fuel can be held in tanks in the fin or horizontal tail surfaces to move the aircraft centre of gravity aft. These are all well-developed systems, their failure cases studied and approved, and their application in association with aerodynamic, structural and engine developments all contributing to the attainment of the ultra-long-range performance of the latest generation aircraft. The ultimate test will be the marriage of these technologies in an advanced aircraft configuration, be it BWB or something stranger, where the basic configuration is unstable but the viability and operating cost benefits are unassailable.

It will be interesting to see how long the electronic system suppliers can hold out as suppliers. In the defence industry, the coalescing of air, surface and subsurface vehicle capability and the acquisition of electronic supplier firms has become a well-established process. Research programmes are still

government sponsored, but overall the streamlining of the vehicle creation process is almost complete. There is nothing to stop major civil aircraft manufacturing firms doing the same thing. Among covert steps in this direction has been the acquisition by Boeing of such organisations as Jeppersen, who supply many of the world's airlines with flight documentation on airports and airspace operations. They are in a position to supply the data electronically, direct to the flight deck. Aircrew training on flight simulators has become a more company-centred activity as well, with Boeing's Altheon offering a bespoke training service to small or new operators, thus saving them investment or subcontracting costs. Airbus strategies are not dissimilar. These are prime examples of additional services that can skew the price quoted when contracts for new aircraft are announced and make aircraft prices difficult to assess.

10.5 Effectiveness

An airliner has to be efficient or it is not a competitive product. Effectiveness comes from the same teams that provide efficiency and whose interest is not solely focused on getting the best that their discipline can offer, but also on optimising the 'performance' with the '-ilities'. These were once conveniently packaged under three headings, reliability, maintainability and testability (R,M&T), but over time the list grew longer and there have been different terms, such as 'value engineering'.

In these areas the designers trade some efficiency, usually because they add slightly to the mass of their contribution and increase its initial cost (and must, to some extent, increase its operating cost). These are design decisions that are justified because they save so much in the overall cost regime. Structural items and aircraft systems have sensors that will detect more than just quantities, temperatures or flow-rates; they detect internal stresses, applied forces, the structure of digital information, and much more, with the sole intent of providing an indication that can be called the 'health' of the product. These are sometimes called health monitoring systems (HMS) and will record or even transmit data for the technical teams that nurse a fleet of aircraft, so that they are pre-warned of an aircraft's status, often even before a system fails. If that is not possible, the information collected will have been selected to allow diagnosis of the cause of a failure, so that repair is effected as soon as possible and in the right place.

This allows airlines to keep to short turnrounds or to have enough pre-warning to reschedule an aircraft that needs unscheduled maintenance. This is indicative of the way that the customer's service reliability targets affect the design.

Overall, change is happening, and happening so much faster than people realise, so that when the cause is associated with the effect, it will seem as if a

quiet revolution has taken place. The expectation of everyone in civil aviation has to be that they are a part of an organisation that will be affected by these changes, which will eventually be absorbed within their sphere of influence. This much will be even more apparent as airline, airport and airspace issues are addressed in later chapters, as they are part and parcel of the 'system' that is involved at this level. It is one reason why interest in such a wide breadth of subjects has to be encouraged and supported in these formative years.

These newer, systems-orientated, teams will be responsible for addressing the impact of changes from outside the immediate sphere of air transport on the shape and attributes of the business itself over time. Five potentially leading scenarios are considered in the final chapter. In these scenarios the cross-element interactions will become clearer to the reader, and the fact that no organisation, or individual, can afford to 'niche' itself will become very evident.

11

Coping with change: the airline's challenge

Abstract: This chapter reviews trends that in the past characterised change in airline operations and also considers newer developments. The way these will impinge on airlines are analysed under viability, compliancy, efficiency and effectiveness headings. The implications of requirements that can be perceived to be imposed by other elements within the air transport system are considered and the ability of airlines to respond to change from these sources is postulated.

Key words: financial viability, yield management, statutory compliance, efficiency, effectiveness.

11.1 Introduction

Airlines serve demand. The simple way to create an airline is to find a lucrative city-pair and offer a service; initially airline life was that easy. Competition was a problem, however, because the easy routes were between busy commercial centres, so the 'flag carrier' at each end of the link would want to net its own share of the loads. As markets were scarce, 'bilateral' agreements were often the gentlemanly way to remove obstacles to progress and were the seeds of future regulations, which still exert a considerable influence on air travel service provision options. The aircraft of those early days were relatively simple too, so airlines were limited to choosing relatively close pairs. If a passenger wanted to fly between two widely dispersed locations, they invariably flew via intermediate stops. The aircraft were so slow that the journey time was often a deciding factor.

Airlines nowadays, while they are still air service providers, are very different in terms of their scale of operation, their reach, the agreements under which they offer services and their clientele. Of all modern businesses, airlines have been among the most profoundly progressive, especially since the arrival of jet-powered airliners. They cannot be accused of being unable to cope with change and are often cited in business circles as good examples of what change can mean in modern entrepreneurial societies.

Table 11.1 Evolution of journey time with aircraft speed

Average airspeed (knots)	Time (h) with tailwind	Time (h) with headwind	Difference (%)
450	10.6	13.85	31
400	11.7	15.9	36
350	13.2	18.6	41
300	15.0	22.5	50
250	17.4	28.4	63
200	20.8	38.6	86

Journey time: 5400-nautical mile journey with 60 knot along-track wind component.

Technology has played a large part in how airlines have expanded their operations since they were embryonic businesses. Modern aircraft have greater payload, achieve greater ranges and also operate at greater speeds.

As one example, consider how speed affects the way schedules are composed. Table 11.1 summarises the out-and-back flight times for a 5400-nautical mile sector with a steady headwind/tailwind, with aircraft at operating speeds that vary from current speeds (450 knots) to those of the 1940s (200 knots). The data show that a journey such as Europe–SE Asia and back is nowadays a half day each way journey. In the 1940s it was almost a whole day each way in aircraft that did not have the endurance to do such a long trip anyway, thus requiring one or more refuelling stops en route.

Airlines invest in technology, and in the majority of analyses the emphasis is on what they get out of the aircraft they use. However, airlines have had to be much more exploitive than just buying the best aircraft and working them harder and harder. With the prospect of airliner attributes reaching a plateau – in terms of speed and range, and perhaps capacity too – the reasons why manufacturers believe that more aircraft will be needed to supply the capacity that will arise from more demand is clear to see.

Note at this stage that, if environmental arguments are used to justify a lower cruising speed for aircraft, the time taken and the time differences between the directional journeys will soon stretch, and the impact of that on long-haul travel, without some very innovative marketing, will almost certainly lead to a reduction in demand.

Technology has offered a lot more to airlines that just better airliners, and the extent to which the airline sector has exploited technology in the way it has encouraged access to services has been significant in the immediate past and seems certain to be even more significant in the future. How this will influence the future is examined under the following four headings, identified as representing the most fundamental management aims in the main air transport elements.

11.2 Financial viability

The most significant airline financial parameter, and also its most carefully disguised, is yield. The topic was introduced in Chapter 6 and, in a simple recap, yield is the amount of revenue generated per seat on a service. Hence a service that attracts 120 passengers at a flat fare of $60 generates $7200 of revenue. If a 180-seat aircraft is used the average income per seat will be $40 and if a 150-seat aircraft is used the average income per seat is $48. The average income per seat is the yield. As the traditional way of apportioning costs is to consider the average cost per seat, yield is a useful revenue-based measurement to set against operating cost.

Aircraft size can affect the yield target that is set for a service. For example, if it was a 0.75-hour duration flight and the operating cost of two aircraft available was $10 000 per hour for a 180-seat aircraft and $8000 per hour for a 150-seat aircraft, the cost of providing the operation would be $7500 with the 180-seat aircraft and $6000 with the 150-seat aircraft. If these data refer to the operation on which a revenue of $7200 has been postulated, the larger type would not show a profit, whereas there could be a profit with the smaller aircraft. This comparison should tell any astute reader, straight away, that an airline sometimes has to be proactive in raising the revenue that an operation will generate (and that operating costs have to be understood and managed carefully – a simple generic per hour cost is rarely used in a genuine airline evaluation).

A further issue to consider is the passenger load factor. A 120-passenger load equates to a 67% load factor on the larger (180-seat) aircraft and 80% on the smaller (150-seat) aircraft. In Chapter 6 there is an analysis (using 'spill factor' techniques) that has investigated the conflicting requirements that have to be considered in this regard. These boil down to the fact that the larger the load factor on a flight the more likely it is that passengers will be deterred from flying through more frequent booking refusals, so while the larger aircraft looks to be the less financially suited aircraft for the route, one vital service quality indicator, the rate of refused bookings, will be better.

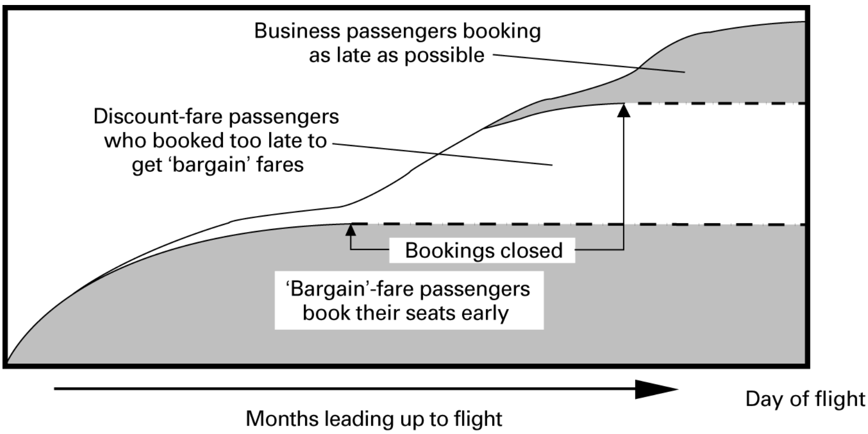
This was all well understood pre-deregulation, but as competitive pressures edged in the yield management game took on a new lease of life, as the temptation to let some flights overfill was now a weakness that could be exploited by new competitors. The role of a yield manager (initially called the 'space controller') emerged as a crucial pivot over which commercial and technical attributes of operations would be balanced. The yield manager had the task of balancing capacity and demand in a way that would leave the passenger satisfied with their fare and terms of service, but paying as much as the airline could prise from them for their seat. The outward sign of this transition in the way that revenue was being managed

was the increasing availability of flexible fares. It is an oversimplification to say that flexible fares were a result of deregulation, as flexible fare policy substantially pre-dated deregulation.

While it was certainly the desire to tailor sales strategies so that revenue sensitivities were milked by the operator, the opportunity to take the necessary steps to do this came from another vital technological infusion, the computerised reservation system (CRS). The great importance of this capability is exemplified by the fact that in the period 1985–1995 approximately, some of the world's airlines were investing at a greater rate in CRS capability than they were in aircraft fleets.

The complexity of yield assessment and the application of philosophies, which are manifold and are under revision on a given route on a daily basis, in the modern yield management system makes the situation very difficult to explain. The next few paragraphs will show, as pictorially as possible, some of the major aspects of what does happen.

Figure 11.1 shows how a yield manager expects consumer price sensitivity to affect the accumulation of bookings over a period of time. Immediately after placing details of the flight in the market, the service will attract the attention of 'bargain' fare passengers. They are the most price-sensitive consumers, so they will book early, accept restrictions on transferability and concede service quality in their quest for low cost. If the flight bookings were left open, there are often enough bargain hunters to fill the aircraft, but the fare they are willing to pay may not generate sufficient revenue to cover the aircraft's operating costs, so the availability of bargain-price seats is carefully metered. The cheapest tickets will cease to become available at the point where the bargain hunters have filled the demand released by the yield manager. Bookings therefore surge again as soon as seats are 'unblocked'

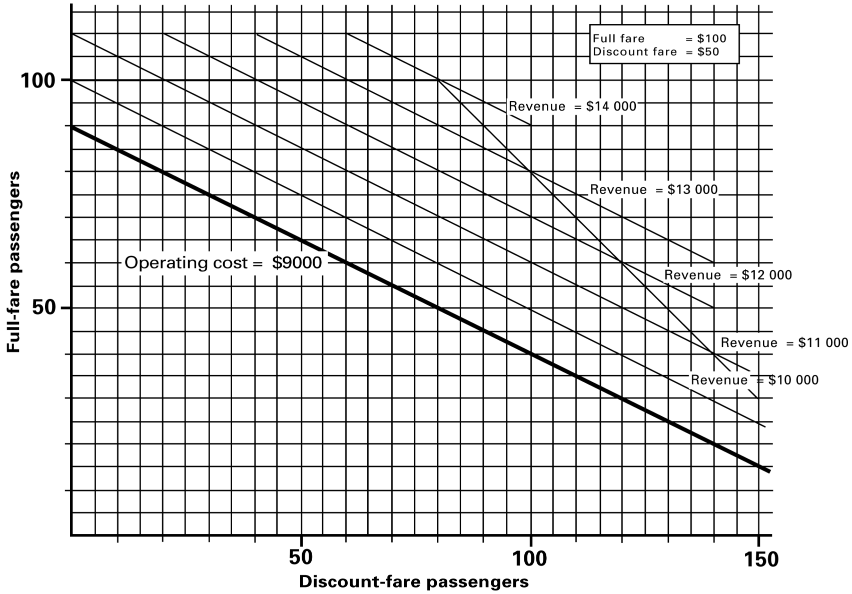


11.1 Timeline schematic of a typical yield management seat release scheme based on a three-tier fare system.

because people are keen to get on the flight, but the seat availability is again controlled by the yield manager. In many respects this is a gross simplification, as the seat offer that will be available now and appearing as the lowest available fare may also have been available earlier. While the seat price will be higher, it is probable that there will be fewer or less onerous service quality limitations.

The reason these cautious steps are taken is based on the common wisdom of the profession that the business passenger will appear late in the day. They are the least price-sensitive passenger, who will pay relatively handsomely for a seat on the flight they regard as essential, whether from a long time in advance, or from a point in time within a few days of the service date.

If this process is simplified down to a \$50 discount fare and a \$100 full fare (this is too simple for most operations, but the visualisation of more than two fares is difficult, and the salient points can be considered in a two-tier fare system) and a 180-seat aircraft is used, the plot shown at Fig. 11.2 can be postulated. The aircraft has been assumed to have an operating cost of \$9000 for the trip. Thus, if the aircraft was filled with full-fare passengers paying \$100 each, revenue would equal costs with just 90 passengers. Alternatively, 180 discount passengers paying only \$50 each would be



11.2 An illustrative yield management diagram for a two-tier fares structure applied to a 180-seat airliner. This diagram shows lines of constant revenue, in excess of the flight operating cost, attributable to combinations of full and discount seat sales.

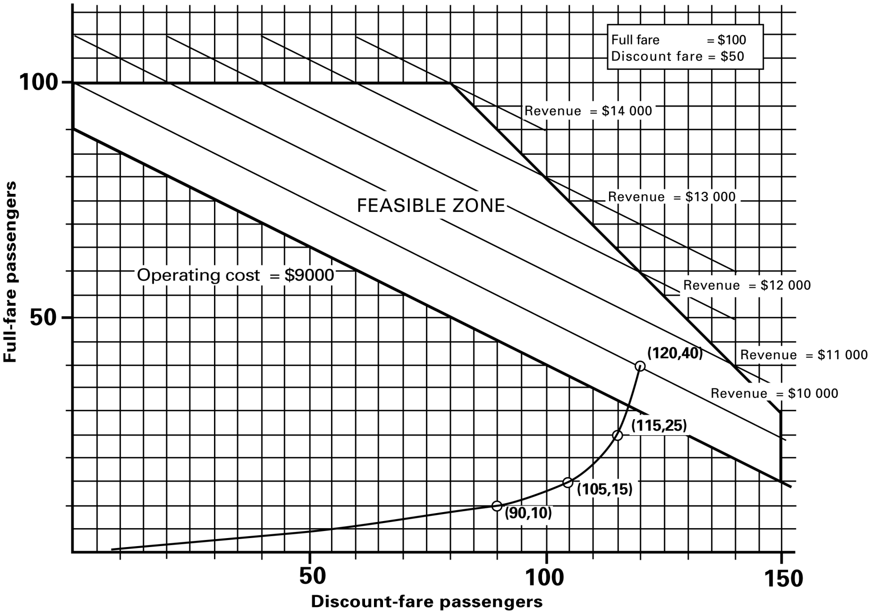
needed to break even at the same operating cost. The diagonal line from the 90 full-fare passenger point aligned towards the 180 discount passenger point represents a line on the plot that will have an economic (i.e. not profitable) passenger load, while above this line is the region in which a profit can be achieved. Based on the fares proposed the revenue that can be expected at various combinations of discount and full-fare passenger loads can be superimposed, and is shown as a series of additional parallel lines.

The combination of full- and discount-fare passengers cannot exceed 180 (the aircraft's seating capacity), which creates a steeper diagonal line. Thus the higher the proportion of full-fare passengers, the greater the revenue achieved. On the plot two limits, one each on the maximum number of full-fare or discount seats that will be sold (set at 100 and 150 respectively), have introduced a vertical and a horizontal line, and where these intercept the diagonal full aircraft load line, they create a graph that is not dissimilar to an aircraft payload–range diagram. As in the case of the latter, the line is an envelope and the only feasible operations are in the space below it.

Because seat and revenue data are superimposed on this plot, where revenue is less than the estimated flight cost ($9000), the operation is unprofitable, and in this region a sales outcome can be regarded as undesirable. However, above this, in a region bounded by the envelope created by the seat allocation policy (and aircraft capacity) and the operating cost line, a profitable operation will occur, and it is in this area of the graph, called the 'feasible zone', where the yield manager has to have steered demand by the time the flight takes place. This interpretation is shown in Fig. 11.3. Note that the seat allocation policy has limited the best revenue potential to $14 000. It could have been $18 000 (all 180 seats sold at $100), but that would have created a minute feasible zone – in fact a line only on the vertical axis – and would have assumed that all the demand was passengers willing to pay the highest price. The airline takes a risk in offering lower fares, but by controlling the supply of seats allows the yield manager to moderate demand for the lower fare.

Also on Fig. 11.3, a time-related booking profile has been plotted; this line brings a time-related perspective to the interpretation. It has been assumed that there is a date from when seats will be sold and that the bargain-hunting passengers result in 90 discount fares being sold, against only 10 full-price seats, by some early date, taking the booking profile to the point marked (90,10) on the diagram. By this time the revenue committed to the service is $5 000.

If the yield manager was allowed to release only 90 or so discount seats on this service, this would force the airline to find an additional $3500 of revenue from full-fare paying passengers (or 35 more of them), making 45 in total. Their prognosis, based on statistical records (which are about the most commercially sensitive material held in an airline's archives), may be that



11.3 The yield management diagram presented in Fig. 11.2 with a time-related booking profile that will result in a profitable operation superimposed.

this is an unreasonable expectation, so they will be running at a loss with an aircraft on which barely 60% of the seats have been filled. To achieve a better revenue result it is essential to recognise and release some of the 'empty' seats into the lower fare category. It has been assumed to result in sales of an additional 15 and 10 discount-fare tickets in two stages. Meanwhile, as the flight time approaches, the full-fare customers are appearing, and at the same time full-fare sales have added 5 and 10 respectively. As these two seat availability decisions have been taken, the booking profile has reached the points marked (105, 15) and (115, 25). However, even at the latter point, with 115 discount and 25 full-fare passengers the flight is set to attain a revenue of only $8250, which is still below the operating cost. This is often the case on typical flights within about 10 days of their due operation.

The graph suggests that if all remaining seats are sold (taking the booking profile vertical from the (115, 25) point, to (115, 65)), the best possible revenue will be $12 250. This would be a handsome profit – $3250 on $9000 expenditure. It would also be a 100% load factor operation, and the chances are that some full-fare (high-yield) passengers will have been refused a seat. Service quality criteria will have been sacrificed in the quest for maximum viability, which is not what the airline wants its customers to see. If the

expectation is that perhaps only 15 further full-fare passengers will be attracted, the decision could be to release 5 more discount seats. If this is borne out by bookings, then the final load will be 120 discount and 40 full-fare passengers. This is an 89% load factor operation that will generate \$10 000 revenue. This would provide an excess of revenue over costs of about 11%, representing a viability and service quality trade-off that will suit operator and user alike.

Airlines pre-build booking profiles for their operations. They are much more 'multi-dimensional' than has been illustrated in this two-tier fare system, because the fares structure can be complex. (It is often simplified behind the scenes by conglomerating similar fares.) The exploitation of anticipated versus actual booking profile performance requires intensive and regular monitoring, and this makes a CRS essential.

The public also has direct access to the booking system nowadays and can modify the demand profiles without realising it. If an airport serves a city that has a successful football team that is drawn to play a side at a destination that is on the local airline's timetable, the sudden demand for tickets will force the yield manager to take a real-time decision that will be exploited to improve the airline's profitability. Such events are often predetermined, and in the interest of enhancing financial viability the seat release profile is blocked, at the push of a button, as the news is broadcast – explain that as good customer service to a football fan!

Yield management processes are used by all airlines, but their implementation can be very different:

- A small, regional airline might use small aircraft, have infrequent services and a very stable clientele, and might not need to invest in CRS, but the airline's stakeholders expect their investment to be nurtured and will anticipate that some yield management process is used.
- Low-cost airlines differ from the more 'traditional' airlines because they use a common seat base, so their service quality criteria are less appealing – basically, book late, pay more and get nothing extra.
- The large international carrier will perform yield management across a range of fares and can even manage the use of each cabin segment: first, business and economy, according to a distinct set of booking profiles. In some airliners the economy cabin is further subdivided.
- All airlines tend to trickle the release of seats for internet booking at increasing cost as the time of service approaches. The economy cabin booking profile in large airlines is similar to that for a low-cost airline, while the higher service quality cabins have their own flexible fares strategies. In these parts of the cabin a travel representative (for example either a travel agent or internal company travel office) will be able to

secure a better deal for a corporate flyer – all the more so if they have an airline loyalty card – than an executive making a direct internet booking.

One consequence of these developments has been an interesting realignment in the highest yield categories. There are some people who eschew personal contact; hence first class cabins are often operated at 40%, or less, load factor, so that such people – recognisable from their political, business or entertainment status (whether on stage or television, or in sport) – can sit in a double seat without having to endure the classic 'hey – I know you!' and the accompanying conversation that can make a short journey seem long and a long journey unbearable. First class cabins have not grown proportionally as the lower-yield cabin section has, and the regular 'business' traveller is isolated from the 'celebrity' cabin by being offered a level of service that equates very closely to first class, even nowadays in terms of seat pitch as well as width. This does not, however, diminish their lust for the perk of an 'up-grade'.

The traditional airlines have consequently come under pressure from a new breed of airline, which caters entirely for the business traveller. Even in the USA, when it was first attempted, the chance to fly between domestic locations on such airlines was not popular enough to allow all-comers to survive. This concept has been revisited now by airlines with long-range service aspirations. It was possible in late 2007 to fly from London to several US destinations by no fewer than three airlines that offered salubrious space at fares that were comparable with traditional airline business class fares. Established airlines are able to flash frequent-flier perks to the clientele they want to retain and advertise a complete route structure, whereas – in these early days – the new 'business class only' airlines are operating on only the most lucrative routes, and with nearly minimal frequencies. By mid-2008 all these US–UK business-only airlines had folded. The risks are as high as the potential rewards.

An associated possibility is evident in the way that some airline managers are beginning to ask whether first class, as a distinct passenger category, will survive, because the equivalent quality of service is already offered in business class. To test the water, some airlines have begun to recreate the original 'business class' concept: slightly improved seat pitch (and sometimes width), and some pampering with regard to menu, but largely through offering more flexibility in terms of go-show/no-show or changing flights (but staying with the same carrier). This can appeal to a thrifty business traveller whose interest is in value for money, rather than just status, and especially if their exact itinerary is unknown to them at the time of booking.

The possibility of the first class cabin being abandoned is being hastened by the unpublicised success of 'fractional ownership' of business jets. If you are a person with a 'brand' name, the chances are that you will travel often,

have a wide range of destinations to reach and will like so much flexibility that you can call for the service you want, where you want and when you want. That used to require that you purchase a status symbol – a business jet – which cost a great deal to buy and your veritable 'fortune' to operate. A fractional-ownership deal gives the user access to what is essentially a new class of airline. They might pay a substantial sum per month for a business jet that is bigger than they would care to consider (but still aspire to) and have a personal (plus entourage) flying experience, with service that is beyond first class, in that the cabin can be a business suite cum lounge and dining area. The cabin crew is bespoke, there are no other passengers eyeing you and the aircraft nowadays are as ultra-long-range as the best airliners. Teeming airport terminals are circumvented – a great perk for someone who does not want to be shuffled among the general public (often not because of snobbish intent, but because of abuse or even the threat of physical violence).

Airlines are still financially astute, but the model of a typical airline is being subdivided into many more branches as time goes by. The days of the 'traditional' airline are not numbered, but their role will be alongside, and perhaps eventually usurped, by the newer breeds – low cost, business only, fractional ownership and others yet to come. The implications on airports and airspace – and even aircraft manufacturers – could be profound.

It is worth recalling that in the 1960s, the doyens of long-distance travel, ocean liners, were so comprehensively eclipsed, as the choice of wealthy travellers was expressed by a preference to fly, that few remained in service, and the traditional shipping lines were soon wound up or reincarnated around the activities of merchant vessels. Eventually, substantial numbers of liners have found their way back on to the sea, but the genre of ocean liners in service today, whose role is to provide serene passage between places that the passenger can enjoy visiting for pleasure, has been a tale of reinvention that is beyond the scope of this book. It is a tale that perhaps has some relevance to aviation – the next generation?

11.3 Statutory compliance

A background to airline route licensing, freedoms of the air, bilateral agreements and the emergence of the 'deregulation' era has been presented in Chapter 3. In the 1960s the regulatory powers of the government agencies that awarded 'licences', and that were applicable to domestic as well as international routes, were an invisible net, and insofar as emerging airlines were concerned this was a constraint with an improbably small mesh. The incumbent airlines had 'grandfather rights' on lucrative routes, and where the airlines were state-owned the alleged connivance between the rule maker

and the airline owner, as both were the same, was often a source of commercial grievance.

The net was unravelled slowly, but often at great commercial risk, by airlines that either stepped through loopholes or whose ingenuity led to legislative reform that widened the mesh in places. In Europe, for example, the rigidity of national boundaries was softened by the increasing flow of passengers travelling for leisure, and with a pan-European legislator there was a door that entrepreneurs could knock on to request reform. Initially, it was surreptitious, but as the implications of small concessions became clear the incumbent, still largely state-owned, airlines began to cry foul. There was enough demand and therefore growth in the non-state-owned airlines (sometimes referred to as 'independent' airlines) for their influence to become substantial. In particular, airlines were beginning to appear that served only leisure travellers. They sold their seats to holiday companies (who were often their almost invisible owners) and did not need to comply with IATA ticketing policy. This did not matter to them or their users if they were offering a point-to-point service. They became known as non-scheduled, or 'charter' airlines. The 'scheduled' airlines, often now well-established household names, had to re-trench. They wanted to compete for the leisure demand, which was growing much faster than business demand, so they started to segment the cabin into economy, business and first class.

When 'deregulation' emerged in the American domestic and international licensing arena in the late 1970s the Civil Aeronautics Board (CAB) that had administered the licensing of routes was lost overnight. While international policy was absorbed within the machinery of state departments, on the domestic scene there was a free-for-all. This was not a technologically driven change, but a change in the way that the regulatory environment was constructed. Also, while route licensing was abolished, there was no free-for-all in other respects, as airlines still had to meet regulatory requirements of competency to be a licensed air carrier and the airports exercised control over the allocation of 'slots' for take-offs and landings.

These developments and the subsequent route-related changes in the regulatory instruments governing access to markets (which have led to the financial restructuring of the way that airlines derive revenue in the more competitive arena that has emerged) are issues linked into the change processes and the spread of yield management techniques described earlier.

The other main impacts on airlines of statutory compliances are in technical and employment law. In the technical field, there has not been significant change in the processes used to define and manage risk for many decades, although safety management system (SMS) philosophy has changed and aircraft operations nowadays are planned with safety cases alongside, rather than following, the economic cases. The popular line is to call for 'propagation of best practice'. The regulator sets the benchmarks for

outcomes, the user interprets these as targets and the process that will deliver performance on those targets is for the user to describe. In all fairness, while this puts responsibility where it belongs, it calls for inspectors that have been active, and thus are knowledgeable, in the field. Otherwise they would be incapable of recognising what is innovative and sensible, rather than what is innovative and either reckless or useless. It is not enough for someone to know merely what the statutory line states and to be allowed to seek compliance and yet not to recognise competence. There are concerns that need to be addressed in this area, and among them is the gradual dilution of national control, especially within Europe, where pan-national safety regulation is spawning a new umbrella of safety gurus. A level playing field is certain to be valuable to Europe, but the levelling, if all competences are to be maintained, has to be achieved by lifting everyone to the same level – not averaging the pre-levels.

In the employment field, the social impact has been considerably greater than would have ever been anticipated, but any statistical analysis of likelihood could have predicted where the businesses now stand. For example, the proportion of female aircrew has increased and continues to increase, with a 50:50 male to female ratio almost in sight. The number of operations nowadays using two-place flight decks that are all-female is considerable. Women have yet to arise in significant numbers in the higher echelons of administration and operations management, but that will be when the tide will have stopped changing and the new status quo will reign.

In customer service areas female infiltration, in what was often a male preserve, is an ongoing process. Considering the greater influence of women as passengers, this is not to be unexpected or unwelcome. An area where the reverse gender-mix change is evident is cabin crew. With sex and age discrimination and racial equality laws proliferating, the glamour-girl image of the typical 'hostie' is about as far removed from reality now as most science-fiction entertainment is from space science.

Throughout the machines and offices of airlines, people are less likely than ever to be tied as employees by pension contracts, and the rate at which businesses emerge, then merge or are swallowed means that the days of employee stability are gone. On the plus side, people will be freer than ever to move where they wish and when they wish. Some hope is attached to the fact that people can seek out satisfaction, not just remuneration. This could be a pious hope, but there will be some truth in it for many people. Good human resource management perhaps should be measured with a bias that recognises the merit in better employee retention statistics, rather than through salary scale comparisons alone. Trade unions are at liberty to be proactive in engendering such change, but whether they will or whether they will believe it is in the employee's best interests to be biased towards employee numbers and pay issues alone remains to be seen. There are

certainly dramatic changes in employee benefits that deserve addressing with respect for a communal voice that will be proactive on behalf of employees rather than just adversarial towards the employers. Meanwhile, airlines often subcontract (or outsource) functions that are an integral part of their product (ranging from aircraft maintenance to passenger handling at airports), and the employee numbers in direct employment are often falling. This has a direct bearing on some measures under the next heading.

11.4 Efficiency

Efficiency comparisons can rarely express the full picture of what has changed in airlines. There are some straightforward measurements that show what considerable change there has been. The hint was given in the previous paragraph, for looking at passengers carried per employee is a poor indicator of efficiency, simply because comparisons across airlines might not be measuring the attributes of like-for-like situations.

Efficient use of aircraft is still indicated, on the whole, by hours per year utilisation. This has tended to rise in short- and medium-haul operations since deregulation, but in long-haul operations, where local time zone influences are unavoidable constraints, the change has been almost negligible. Some observers see this as a clear indicator that the extension of the low-cost airline model from short- to long-haul operations is unlikely. It is difficult to measure how efficiently in terms of fuel usage an aircraft is operated, but a few indicative issues can be observed. First, the best fuel performance is achieved if the aircraft is being used to its maximum payload and range potential. In fact, this is rarely ever the case. As the decrement that differentiates a flight with about one-half the feasible range with a given payload from one with the full range (especially for a long-haul aircraft) is relatively small, there is little to choose between them. A more important aspect is whether the aircraft is operated at optimum climb, cruise and descent conditions. These are three important requirements:

- Optimum climb would require uninterrupted climb, which is a rarity in the congested airspace around busy airports, as the departures have to be vectored away from or above/below the arrivals.
- Optimum cruise is so-called 'cruise–climb', whereby the aircraft maintains a fixed speed but climbs gradually as fuel is consumed and aircraft mass decreases. This cannot be offered in most air traffic service environments, so short/medium-haul operations tend to fly at one altitude (and take a considerable penalty on cruise fuel usage if the aircraft is lower than its best altitude) and long-haul aircraft tend to fly low at first and then to step up to higher altitudes as fuel is consumed,

subject to there being adequate airspace to accommodate them. This is called a step-climb flight.

- Finally, the best descent profile is a steady continuous descent, with the aircraft remaining 'clean' (flaps and landing gear retracted) until as late as is reasonably possible, so that drag is minimised and fuel burn moderated.

On top of these flight profile issues, the route should also be as direct as possible, subject to a track-change not being recommended to pick up a following wind, which will reduce flight time enough to offset the fuel used in manoeuvring into the tailwind condition. In respect of all of these issues, flight operations are in the hands of the air traffic service providers, who will look after a flight throughout its journey. There is more to be said on this in Chapter 13.

Efficient use of employees is best reserved for measurement of essential employees. The ability to get better use of aircrews is limited by safety legislation, which imposes flight time limitation (FTL) criteria. Examples of these are presented in Chapter 3.

Within ground-based operations the ability to use people efficiently is often dictated by the airline's schedule. In a hub-and-spoke operation the airline will have continuous activity at its hub, but at outstations the workload will be patchily distributed throughout the day. In large international operations, an aircraft might only pass through an outstation once or twice weekly, and it is sensible in this case to accept a subcontracted service from an organisation that seeks to use its employees efficiently by handling the requirements of several airlines. They know the local circumstances and can thus function well within the community, but the downside is that they will be tied to several operators, perhaps some of them the airline's own competitors, and thus the quality of service will not always be assured. The key document to achievable acceptable performance is a service quality agreement (SQA), which specifies the level of performance measurements that will trigger investigation and may even lead to the review and rescinding of contracts. The greatest difficulty in such cases is finding adequate independent information. Sometimes SQAs define attributes that can be monitored through reference to computer records that might be falsified. Complaints are therefore monitored. If a check on performance, such as closed-circuit television (CCTV) monitoring of the service rate in passenger handling functions, is available, checks are often made to correlate reported and observable service qualities.

11.5 Effectiveness (attaining service quality criteria)

Finally, effectiveness has entered the debate already, with passenger service qualities aspects being alluded to. The effectiveness of any service attribute that detracts from efficiency can be justified if the net effect is to improve the quality of service for users and the financial impact is acceptable.

Comparing low-cost and 'traditional' airline operations, the low-cost airline offers a 'no-frills' service, implying that all at-seat service requires payment above the fare. For many air passengers this is not a problem. Indeed, in a flight of up to around two hours' duration a passenger will not normally crave food and drink, and on the occasions they feel they do need refreshment they are likely to be willing to pay a premium for it. This is no different to the service attribute model that people accept in long-duration surface transportation modes.

On air services where a range of fares is applied, the in-flight cabin service can vary greatly. An economy class passenger and a first class passenger will be served at seat, but the ratio of passengers to cabin crew will be considerably different. In economy the passengers will dine when the food is served. In first class the passenger will be offered food and served only when requested.

Similarly, the seat is clearly larger for the higher-fare passenger and might even be a bed. A personalised space is being offered on newer aircraft, with storage cabinets, seat/flat-bed, electronic media suited to entertainment or business applications, a small desk, and so on. To preserve privacy there is a trend towards cubicles, designed by teams that have learned how to pack the most service into the smallest space in yachts – an interesting retro path from maritime to aeronautical endeavours.

Service quality differences can also be apparent long before the flying experience with, for example, airports providing special lounges for high-yield passengers. The airline might have a range of lounges at its main airports (or use lounges operated by appointed service providers at less frequently used airports). In their own space a service that replicates the airline's own brand will be essential. This will include food and drink on demand and access to information technology and telecommunication services. Spacious toilets have always been high on wishlists, and nowadays there are even shower rooms. This all comes at a considerable price when the airline is fighting for terminal floor space with retail concessionaires. When the flight is ready to board such passengers will often be pulled on last of all, so that they are not kept waiting.

Some of these passengers will have a special status with the airline, as a frequent flier or commercially important passenger (CIP), and will be identified: once on board they will be seated in preferential locations and served on personal name terms. This is all tracked in the airline CRS, and

the passenger manifest tells the lounge staff and cabin crews of each individual's preferences and even associated itinerary, so that should there be a disruption to their current flight or related events, they have alternative arrangements in hand even before the passenger knows of the problem. None of these service attributes can be regarded as indicators of efficiency, and many a low-cost airline manager will refer disparagingly to the pampering that such users receive. For a corporate traveller the efficiency that they derive from being able to conduct work on the move or to reschedule their affairs will be regarded often as worth the extra cost to them. This is where 'efficiency' is a misnomer if packaged from a sole stakeholder perspective and effectiveness is an attribute that has to be held and valued alongside all the other attributes – financial viability included.

In the discussion of financial viability the high-yield sector was shown to be vital for profitability in current operations, and the great lengths to which airlines will go to make sure that the service quality they receive is always apparent to the user has been shown now to be achieved at a cost in one further quarter – in the airports. Interestingly, the lower density routes into which the airlines might want to expand, but which are being served increasingly by fractional-ownership business-jet operations, are often attractive because they avoid busy commercial airport terminals completely.

In retrospect, 'deregulation', in that it has unleashed what many would call 'market forces', has done a lot to polarise the airline business. The low-cost and traditional carriers are the main players. In most cases the low-cost carrier (LCC) is a new start airline, designed to exploit the efficiency of the latest aircraft by having the maximum number of seats and highest reasonable annual rate of utilisation, both attributes that reduce the seat operating cost. Seats are offered with relatively low (even negative) operating margins, but with a sales policy that will ensure profit (over a range of services) comparable with traditional airlines. The passenger gets what is offered – a seat between A and B. The 'traditional' airlines are often long-standing airlines, whose operations have been drastically overhauled, maintaining their allegiance to the established air traveller market, where the service is as valuable as the seat and which also offer a service competitive with the newcomer airlines. The further fragmentation of the market with specialist high-yield service provision, in airliners or business jets, is a newer phenomenon that has yet to be fully integrated into the models of the air transport system that are in widespread use.

12
Coping with change: the airport's challenge

Abstract: This chapter reviews trends that in the past characterised change in airport operations and considers newer developments. The way these will impinge on airports is analysed under viability, compliancy, efficiency and effectiveness headings. The implications of requirements that can be perceived to be imposed by other elements within the air transport system are considered and the ability of airports to respond to change from these sources is postulated.

Key words: financial viability, statutory compliance, airport security, efficiency, effectiveness.

12.1 Introduction

There are few airport managers who, having taken a break, come back and find things as recognisable as they might expect. Change in the airport scene has been more piecemeal than in other parts of the air transport system, but with the cumulative effect of many changes coalescing to create periods of rapid change. Fascinatingly, the rate at which matters continue to change shows no signs of respite. The preceding chapters have shown that the characteristics of aircraft and the services that airlines might plan to operate, will continue to introduce change. Additionally, and unfortunately, there is one further significant change overall that has affected virtually all airports worldwide, and that is airport security.

Security procedures at airports are reactions to the threats that arise from tensions – social, economic, political or even religious – that affect communities. They involve aviation because of the perceived vulnerability of aircraft to terrorist action, and the airport is where the threat is most imminent or most detectable. There is nothing that civil aviation can do *inter alia* to solve these problems. It has to conduct its business in such a way that threats are understood, and counter-measures are put in place that will have an acceptably high probability of success to counter, or deter, life-

threatening actions. This is an example of where the full scope of the interaction of the system has to be taken into account by all civil aviation stakeholders.

The airport is therefore often a servant to the service provider, but an airline, having found a potential and desirable service, cannot necessarily expect the airports they choose to use always to welcome them. Airports have capacity issues to address, perhaps refusing to accommodate a service or forcing the service proposal to operate at less favourable times. All these are strictly air transport issues, but there are also political issues that need to be addressed. Within the air transport legislation arena this can mean accepting the circumstances imposed by bilateral agreements and freedoms of the air, and deeper into the political arena there may be other national and even international political agreements (or disagreements) to take on board.

These are factors that all impinge, eventually, on the way that airports are managed and that make them all so different, which in turn makes airports often the most varied, and most interesting, of all the elements in the system. Even so, the managers themselves are held to the same rulings as the management teams in other elements, and it is through the four windows of viability, compliance, efficiency and effectiveness that change is now addressed.

12.2 Financial viability

The question of how much viability can be differentiated from profit becomes very clear when the financial accounts of many airport are investigated. At airports throughout the world where traffic is stable, but perhaps unimpressive in terms of volume, the revenue raised from charges will often more than offset the operating cost, assuring the owner(s) that they are in charge of a profitable airport. However, the cost of investment in infrastructure, from runways through buildings and even vehicles (fire appliances that are capable of meeting the requirements of protecting commercial operations rarely come with less than a $500 000 price tag) can overwhelm the annual operating cost. The belief has always been that large international airports were proverbial examples of 'a licence to print money'. This can be close to a true remark wherever there is a well-established and well-used airport. It is less true as one slides down the scale through regional airports to small local airfields. In the latter case, where the land value and its semi-rural use to provide occasional batches of silage to local farmers offsets substantially enough the fees that can be teased from a local flying club and based on visiting private aircraft owners, a situation is reached that does not compare readily with the situation regarding airports with commercial operations.

All aerodromes that handle public scheduled services need to offer facilities that meet recognised operations standards that often stretch costs. As well as meeting the cost of a set of fire appliances there is a need to recruit trained (or to accept the cost of training) competent fire-fighting staff, who can be rostered on shifts that provide full coverage throughout extensive operating hours. The navigation aids and aerodrome lighting systems will be expensive and carry operating costs for maintenance and refurbishment or renewal. There will be air traffic staff services (again with equipment and staff costs involved) and of course the costs involved with the terminal, its apron, the car parks and even access facilities need to be considered.

In the mid-1980s, there was a political desire in the UK to take all airports into private ownership. British airports were like many other airports worldwide in that they had started out as municipal airstrips and had aggregated capabilities step-by-step over several decades, becoming important travel hubs to their communities, but at the same time a draw on municipal funds. Very few were purpose-built civil airports, some having started as military aerodromes, but the common denominator in all cases was that their running costs were absorbed, in essence subsidised, by local public-ownership enterprises. The local authorities, in turn, could dress these as travel utilities and pass the cost of infrastructure development on to central government. The local councils pocketed the financial reward from successful operations, but subsidised the businesses through funding requests. The processes of central government decided these were not costs that should be borne by the taxpayer. They wanted the enterprises themselves to become private entities and to be free to compete for money on the financial markets. Thus airport 'privatisation' (not unknown before the mid-1980s, but it was rare to find examples) became a phrase that defined a watershed in airport history. The UK model was applied by wholly or partially privatising airport operating companies throughout the nation, even selling off the major state-owned airport company, and it has since been widely recognised as having merit in many nations worldwide.

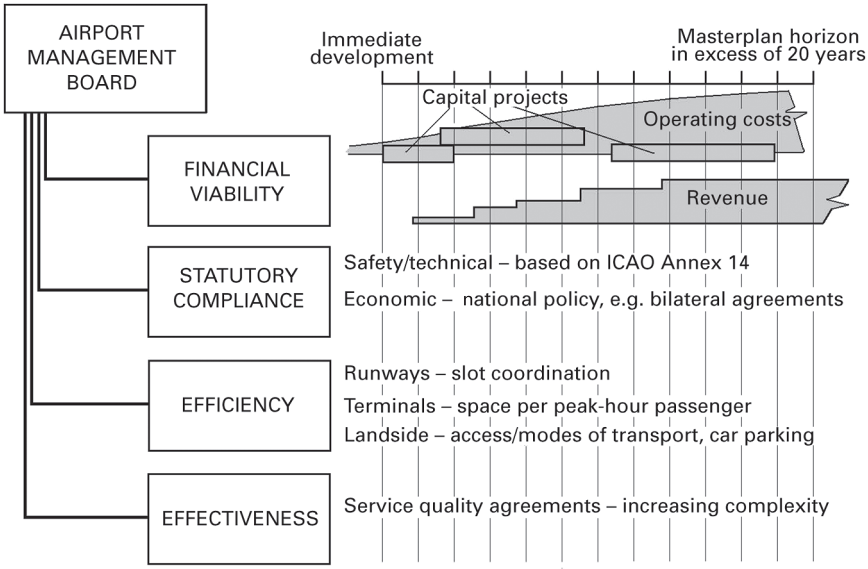
The traditional management board of an airport had been a group of local business leaders, and a number of the individuals might have brought the benefits of some aeronautical knowledge, but this was not always essential. The 'privatisation' initiative required airports to evaluate their assets, draw up their business case and to offer the business for sale on a shareholding basis. In many cases, municipal owners would offer only 49% of shares, thus retaining a controlling interest. This has been maintained at some airports, although many local communities that took this route have since sold even their shares, often with considerable profit, and have therefore shown to have contributed directly to local prosperity through the local realignment of airport ownership. Major airports throughout the

world are still often owned by multi-national, fund-based or industrial enterprises.

One aspect of privatisation has been a realignment of viability criteria. In order to raise cash, surrounding land has often been sold or leased for development to generate single payment or rental income that will supplement the traditional aeronautical revenue stream. The importance in modern airport accounts of 'non-aeronautical' revenue generation is unmistakable. Some airports that have had large land banks on which they had planned expansion have chosen to squeeze what they can out of existing facilities, through capacity enhancement programmes, and to release the land for the creation of enterprise zones.

In some cases an aeronautical edge has been retained, with – where local political circumstances would permit – 'duty-free zones' (sometimes called 'freeports') established. These can attract international businesses that need to import and export materials and products, and they benefit from tax incentives. These developments boost local employment and can inflate national import and export statistics. Where a direct airport-related development has been possible airports have attracted aircraft maintenance and repair organisations (MROs) and fixed-based operators (FBOs). However, these are often the least lucrative of the diversification options. The more attractive aeronautical-related opportunities arise when a parcel or mail-service operator chooses to use the airport as a distribution centre, with international overnight parcel operations provided by aircraft. This can generate revenue from movements in hours of operation where the impact on passenger services are small (between 2200 and 0600 hours overnight), but the dichotomy is that the local area will be subject to night-time jet aircraft operations, so the cost of noise-abatement procedures and noise-protection programmes have to be factored into business plans. The certainty is that not all local residents will feel they are best served by such policies. Of all the options, the least risky for a management team is to use land to accommodate businesses that can benefit from the location. The site can boast good air links worldwide, and often has good local surface infrastructure links.

The downside of such development is that the land would not be available, and perhaps indefinitely, for aeronautical use. This begs the question of what functions an airport is expected to fulfil in a community. If it is seen as just aviation's equivalence of a bus or railway station, it will not necessarily be able to make ends meet financially. If it performs other functions that allow it to prosper as a business and that simultaneously provide employment and prosperity, then surely it is a better integrated part of a community? The corollary to this argument is that bus and railway stations can be developed according to similar principles, albeit they tend to be more city-centre located. An aspect of this common thread of interest is



12.1 An airport management board has to balance the same parameters as an airline, but their development horizon is often over 20 years in the future. Assumptions are based on traffic forecasts and many other time-dependent variables, adding to the levels of technical and commercial risk.

that well-established surface transport companies have often been the enterprises that have bought into airports. Notably, very few airlines have chosen to buy their own airports.

12.3 Statutory compliance

Some statutory compliance issues have been mentioned already, as they impinge directly on operational facility infrastructure and staffing requirements. To be awarded a licence to serve as a commercial airport, each location has to conform to ICAO Annex 14 requirements or national standards that are based on this document. The requirements place a responsibility on the licence holder to set out technical compliances, referring to airport configuration, physical characteristics, and so on. This requires the approval of an aerodrome manual that expresses specific procedures, including a comprehensive safety management system (SMS) statement.

An airport must be managed by a board (see Fig. 12.1), and whether privatised or in public ownership its financial and decision-making processes will need to be approved by the national regulatory authority. The national regulator will look for safeguards against malpractice and risk-mitigation

procedures, and if an airport borrows from commercial sources it will need to do so under strict guidelines.

Increasingly airports are coming under scrutiny with regard to environmental impact and will be expected, where commercial operations are sizeable, to conduct studies that show the expected extent of air and ground pollution, and airport noise. The procedures to mitigate circumstances where the statutory criteria might be jeopardised must be clearly stated, costed and approved for expansion to take place. In the event of a sizeable physical development, such as a runway, apron or facilities including terminals or even aircraft maintenance, the planning permission might hinge on a public inquiry, which can take considerable time and cost. In all cases, airports have to be developed within permitted planning regulations.

As has already been described, security aspects have become central to many aspects of airport operations, and their implementation has become enshrined in its own legislation. Until relatively recent times, security was treated largely as an adjunct of safety; initially hijacking was seen as the major threat, but then terrorism aimed at the airport itself, as well as aircraft and their occupants, has emerged as an equally important security issue that must be addressed.

Initially, airport perimeters were fenced to keep people and animals outside the boundaries, so that they were not put at peril by aircraft operations. Nowadays the requirements for all public-use civil airports is to have a fence line that is very definite, of specific minimum height, with relatively deep penetration in the ground and a durable form of construction. It has to be maintained, and the cost of installation, inspection and general repair of this one item can be a considerable expenditure on any airport's budget. In some cases there may also need to be sophisticated monitoring, using lighting and infra-red and CCTV cameras perhaps. Intriguingly, the perimeter length of airports, whether they handle a few tens of thousands or several million passengers per year, can be about the same. This adds to fixed operation costs, and exemplifies one element of operating cost that makes the operation of small airports less commercially attractive.

Security concerns increasingly focus on the establishment of procedures that address unlawful interference with air transport activities. It is essential to ensure adequate detection of unlawful intent and as covertly as possible. The covertness of security in the passenger-handling areas of airports has become an almost obsessive governmental requirement as terrorism has increased in scope and sophistication.

Even so, there is also direct security. Nowadays all passengers are aware of the security process and are wise to give themselves extra time to pass through the numerous stages of inspection. The official list of unlawful actions that should be prevented, according to ICAO Annex 17, are:

- unlawful seizure of aircraft in flight
- unlawful seizure of aircraft on the ground
- hostage-taking on board aircraft or aerodromes
- forcible intrusion on board aircraft, at an airport or on the premises of an aeronautical facility
- communication of false information such as to jeopardise the safety of an aircraft in flight or on the ground, of passengers, crew, ground personnel or the general public, at an airport or on the premises of a civil aviation facility.

The list shows that the concerns are not just about what might happen on a flight, but what might be happening, which should be detectable, before a flight.

The security-restricted zone that is required to meet ICAO regulator needs is expressed as a risk area where there shall be access and other security controls. It is recommended to include 'aviation passenger departure areas between the screening checkpoint and the aircraft, the ramp, baggage make-up area, including those where aircraft are being brought into service and screened baggage and cargo are present, cargo sheds, mail centres, airside catering and aircraft cleaning premises'. It seems inevitable that security, which did not even feature in airport terminal designs in the 1960s, will be a major part of the design of terminals forever.

12.4 Efficiency

Given that no two airports are alike (even if some can be highly comparable in terms of layout or operations), finding efficiency criteria is not easy. Consider size, for example. Small airports need a decent length of runway, but by the time that necessary safeguarding has been applied, it will often be similar in area to a much busier airport with a similar, or perhaps slightly longer, runway. Measuring airport area and trying to correlate that to productivity through annual traffic data is not a safe criterion for evaluating efficiency. It is what an airport does that defines how efficient it is.

Certainly some measure of throughput and the linking of that to the available infrastructure is desired. Runway capacity has been described in Chapter 7, and the best that an airport can do, in aeronautical revenue terms, is to utilise that capacity as well as possible. An airport that starts small is often a single runway with minimal taxiways, apron and terminal. As traffic demand rises, because it is often driven by the diurnal habits of travellers, movements tend to bunch into peak hours and there are often peak days (especially at tourist destinations, where the demand is geared to serving nearby hotels). This can lead to a need to invest in new taxiways, designed to minimise runway occupancy time, so that the peak hour

movements can be handled with as little delay as possible. Some extra apron space and terminal passenger facilitation area will also be required, and an adroit manager will phase these in stages.

Often the link between them is so close that a few sizeable phases are better than a series of smaller ones, so efficiency and financial viability coalesce in such decision-making. The efficiency of an airport can therefore be measured in terms of such parameters as movements/hour per runway, average movements per apron stand and peak-hour passengers per square metre of terminal area. These are relatively easily determined characteristics and are often used to rank airports in terms of traffic handling efficiency. Where a measurement shows 'low' efficiency, the positive way of addressing this information is to regard the airport as one with development potential. Certainly, the lower the measurements in such cases, the more likely it is that, without some degree of diversification into non-aeronautical revenue generating areas, the airport will be financially at risk.

The interpretation of any ranking processes is never as straightforward as looking at the relative scale of a few simple statistics, however. In particular, the nuances that will have moulded the shape of the passenger demand need to be understood. An airport that handles mainly scheduled passengers typically will offer more terminal space than one that handles mainly low-cost passengers. This seeps into the details, with fewer check-in desks, security and immigration channels and baggage reclaim belts apparent in airports biased towards low-cost operations.

As an airport expands, the annual growth of traffic statistics forces a realisation that there is a point where operational concepts might need to change. It is typical, for example, to expect an airport that starts with a small single-floor terminal to set its sights on a two- or three-floor terminal at an approximate annual passenger throughput level. When scheduled service operations did not include low-cost carriers this was often an accepted need when around 3–4 million passengers per year were being handled, but with low-cost terminal facilities being regarded as needing to be nothing more than a single canopy in which walls can be moved and extensions bolted on in successive seasons, there are examples of single-floor terminals that handle many more passengers per year. Leisure destinations are similar, and they have been examples that have set this trend.

A 10-million passenger per annum terminal can require up to 45 000 m^2 of facilities space. If this is not to be unnecessarily deep – often a design requirement based on the space available between the apron and landside facilities – the terminal is always being stretched. At 45 m deep, the single-floor terminal is 1000 m long. Clearly, if there are two floors the length reduces to 500 m or so. These are dimensions that create passenger-handling headaches, as a passenger arriving at the 'wrong end' will have a considerable journey before they can even use facilities; if the internal

processes take them back along a parallel route, a total processing path of over a kilometre for some passengers is soon a frequent occurrence. Some terminal designers have set the limit at 10–15 million passengers per terminal, and would state that is a break-point in the development. Above this level, there would need to be a second terminal and that then begs the question of where this will be located relative to the first terminal and the rest of the airport infrastructure. Some terminals have struggled to meet the criteria quoted above and some have exceeded it handsomely. At Atlanta's Hartford Airport, designed in the 1970s, the design target was already 60 million passengers in a *single* terminal. With tens of thousands of passengers to accommodate in the peak hour alone, this was a formidable design target, but the way to do it was derived from understanding the passenger flows. Atlanta is perhaps the best example of an airline network hub in the USA, and with passengers arriving, transferring flights and departing, there was no need for a 60-million passenger per annum check-in or baggage reclaim facility. As most of the transfer demand was domestic, the terminal designer looked at airline requirements, and designed the airport as a main terminal – in which the passenger originating from or arriving for Atlanta and its surrounding areas were handled – and a set of parallel terminals, called satellites, that were almost 'piers' (although sizeably scaled) around which the incoming and departing schedules for individual airlines could congregate. If one flies in/out of Atlanta using the same carrier (or a carrier with a code-share) the terminal design is flexible enough to accommodate the majority of such connections on one satellite. The transfer passenger walking distance is thus greatly minimised. This exemplifies innovative thinking and taking a systems-wide approach to design, in that the airlines were consulted and used to evaluate options before the terminal was built. Atlanta was the first such airport, but it has often since been copied, wholesale or in part.

Runways are strips of paving that cannot be physically reconfigured. Their use is a function of taxiway access and egress configuration, and the way they are supported by approach and runway lighting, navigation aids and air traffic service provisions, which have the capability to handle the demand at the capacity that the runway can provide. The aircraft movement rate that a single runway can handle is finite, around 195 000 to 240 000 movements per year (see Fig. 7.6). This assumes it has very comprehensive taxiway, lighting, navaid and ATC support. Assuming that this operational status is achievable, it is necessary for an expanding airport to start thinking about a second runway long before the 150 000 movements per year mark is reached. If by then the margin between demand and capacity is only 45 000 annual movements, at a 5% annual growth rate the new runway provision is required in barely five years. When circumstances are favourable – meaning that the land is available and the necessary planning approvals for

expansion are granted – the design can be completed, contracts let and the runway constructed in such a timescale. This is one example of the commercial risk involved in airport management. The cost of such a development will be sufficient to absorb a large slice of investment, and the likelihood of it being used at a book value of better than 50% efficiency for several years is dependent on traffic growth following a course that has been predicted from several years – a substantial proportion of a decade – beforehand.

The frustration of many an airport manager, fuelled by the desire to serve the community diligently and chastised for running an overcrowded and inefficient airport, and yet having to endure protracted and expensive public inquiries, is not hard to find. As these notes were in preparation the UK government hinted that it would mollify the planning procedures at airports where the national interest is served by expansion. There are traffic targets for most of the major and regional airports outlined in a White Paper, which sought to look 30 years ahead (from year 2000), but despite this initiative and these good words, thus far the experience is that public concerns about the overexpansion of airports will continue to result in a protracted development process. The UK experience is similar to that of many other European countries, where airport capacity expansion is being challenged almost routinely. In the USA there is less public concern, which is probably borne of the wider acceptance of air travel as the best mode of transport to use between major cities, and the fact that land is more readily available.

The only way to accommodate demand at an airport where the traffic capacity limit is being reached is to allocate movements to 'slots'. The airport tends to want to state how many slots it will allocate in each period. (Usually an hourly arrival and departure rate is defined, with room to shift the emphasis from one to the other in various hours.) Airlines vie for slots, and IATA is the facilitator at the twice-annual slot coordination conventions that are vital operational planning forums for airlines and airports. Airports that are involved in such a process are said to be 'slot-allocated' (sometimes also said to be 'capacity-capped'). For any airport it is a dubious kind of premier league in which to have your name quoted. A prime consideration in the convention is to 'coordinate' to the extent that each operation is associated with departure and arrival slots at realistic times. This is vital to ensure that slot allocation is done realistically, but the process is essential to ensure that airports are faced with loads that are not beyond their capacity. Slot coordination evolved in the late 1960s in the USA and was adopted by a few major airports in Europe in the 1970s. It has since become an integral part of the summer and winter season planning cycle for all the slot coordinated airports.

A slot-allocation process, because it is invariably in place to protect service quality when capacity is only just adequate to meet demand, does

suggest that an airport will score good points in any 'efficiency' survey, but the equilibrium between efficiency and good customer satisfaction is a delicate balancing act.

Slot allocation will re-emerge in the next chapter, when the allocations made by en route flow-controller operations in airspace issues are considered. These are developed in conjunction with the airport slot coordination process.

12.5 Effectiveness

Still with one eye on efficiency, attention is now directed to effectiveness, as the relationship between the two has become part and parcel of discussion already, while the debate has been concerned almost wholly with the runway. The change of orientation will also be associated with a change in the components of the airport in which these characteristics are discussed, as the same dichotomy that affects runways plagues the development of the airport terminal. The way in which airports are affected as a result of changes in the way that airlines develop their seat-sales strategies has little significance at the runway – they are all movements, irrespective of the carrier's commercial justification for luring passengers to use its service – but in the terminal, the airline's service quality criteria can have an enormous impact.

Left to their own free will, an airport operator can choose to provide a service capability that will range from superb to the bare minimum. Superb service implies spacious facilities and a high probability of prompt service at any function offered within the terminal handling processes (distinctly different for arrivals and departures, as outlined in detail in Chapter 7). Bare minimum service is clearly one where space is at a premium and service is far from prompt, but setting limits that describe what is good, acceptable, poor and so on is often difficult. Table 7.5 has presented a sample set of IATA level of service (LOS) criteria that illustrate one way of quantifying these distinctions. These can be applied generally, taking account of all the facilities at an airport, or by considering subsets of the complete facilities, thus assessing service quality or effectiveness with regard to the operation of a particular airline. The latter course is essential to collect information that will support the justification of service quality criteria promised to a particular client.

The essential agreement between airlines and airports in this regard is the service quality agreement (SQA). This is a jointly drafted document, which, in some cases, might be simple and non-binding, but regarded as a statement of intent. In many cases, however, the detail is considerable, and the SQA is effectively a binding contract between the two parties. Wherever possible, means of measuring and thus of monitoring service attributes that are

defined in the SQA will be available or implemented, and the agreement will express remedial actions and timescales if service standards do not meet requirements. There will be penalties, and in a sensible agreement incentives too, applicable in respect of airline and airport operator contributions to the agreement.

The ICAO Airport Economics Manual offers a checklist for the contents of an SQA. The elements proposed are:

Service elements:

- a description of the facilities and services to be provided
- the conditions of service availability
- the service standard
- the cost versus the benefit of providing that service standard
- service escalation or de-escalation procedures from the current service standard.

Management elements:

- a description of how service effectiveness will be tracked
- a description of how service effectiveness will be reported and addressed
- a description of how service-related disagreements will be resolved and
- a description of how the agreement will be reviewed and revised.

The source states that success depends on critical factors, such as close consultation, joint agreement of service standards and the careful selection of criteria that reflect performance in essential areas. They categorise the range of SQAs under four headings:

'One-way', reflecting commitments by an airport
'Two-way', reflecting mutual agreements by both the airport and the airline(s)
'Non-financially incentivised' and *'financially incentivised',* whereby in the first case voluntary commitment is encouraged, without detail of implementation, or in the latter case commercial incentives and penalties are associated with each SQA parameter.

Every SQA, while following a principle format, will differ in detail. The detailing of airside, terminal and landside facility service standards will probably be evident in all examples, but at some airports there will be a stress on, say, transfer passenger service standards, while at other airports these may go unmentioned.

An example of the way that change is occurring, through technological impacts on society, which leads to the two parties having to incentivise one another in ensuring that change is accommodated in a manner that will suit users, is in the question of check-in performance. Check-in, a few years ago,

was a simple matter. The airport agreed to offer a given number of desks for a given period, per flight, and if they had responsibility for an agent who handled the check-in process, agreed the maximum queue length and average passenger wait time in the queue that would be anticipated. The system would then record as part of the monitoring process. (This could often be achieved cost-effectively by 'sampling' security CCTV camera recordings.)

However, airlines will now often determine attributes of interaction at check-in by offering traditional and self-service and remote (including internet) check-in. Associated with these developments is the concept of the bag-drop desk, which will usually occupy a conventional check-in desk location. This means that the airport is less able to address service quality issues and the SQA becomes a more fluid agreement, which requires the resolution of issues through joint actions.

Combine the service situation with the issues that arise, from the airlines' perspective, from the banding of passengers into high-, medium- and low-yield categories, and the potential complexity of agreements becomes apparent. The SQA for each category might be subtly, or even drastically, different. An airline will want their high-yield passengers to get priority check-in, perhaps priority security access and certainly will provide (and pay for) a lounge, where the passengers can conduct pre-flight business or rest without being in a busy public area. Their low-yield passengers will get little priority in any of the sectors mentioned. Even so, the airline will not expect them to be herded. They want them 'streamed'. Providing the capacity to meet such demanding objectives is often too onerous to consider as worthy of a simple quality indicator, and it is not uncommon for the airport to agree a service standard that is expressed in terms of minimum and maximum values, or attainment targets that are valid if achieved on, say, 90 or 95% of occasions. The airline can choose to use discretion if the 'tail' of the distribution that this kind of expression represents seems to them to deserve some action.

Some airports have already begun to be proactive in terms of SQA, and will meet potential or new customers with statistical evidence of provision and performance, and ask that these form the basis of an SQA. The range of data offered is sometimes bewildering, including such data as ratio of passengers/flight information displays, based on a statistical average day or hour. This can mean little, given that there can be a need for many small displays or a few large displays and the choice will be governed by terminal configuration. The ratio of passengers/toilets is perhaps more akin to what the customer would prefer to see, and here they might also want details, such as the distribution of toilets in a terminal, so that they can determine that there are such facilities available throughout the passenger-handling processes.

Overall, airports are complex and often overlooked. The users (airlines) tend to measure their value first and foremost in terms of volumes of passenger access, second in terms of equipment compatibility and only latterly in terms of how efficiently and effectively they can fulfil their expectations. Often, the latter are operationally constraining factors, and the resolution of airport operation dilemmas is best viewed jointly, perhaps through a regular committee on which major users have a representative and where the trade-off across the four management perspectives cited can be reconciled in terms of impact on the airport and the users alike.

This is a noble view of the aims at this point, as any such committee nowadays tends to be one where the airport has to justify its actions and the airlines are their judge. The biggest change in airport management will occur when airlines begin to accept that the airport, while it is a facility they pay to use, is just as important to them for passenger satisfaction reasons as any part of the airline inventory. Indeed, putting this observation on record as the way ahead for airlines and airports sets the scene for begging understanding of more enlightenment overall from a proportion of airline managers, as the same quality and interest trade-off will become an issue of debate when the final element, air traffic service, is addressed in the next chapter.

13

Coping with change: the airspace challenge

Abstract: This chapter reviews trends that in the past characterised change in airspace operations and considers newer developments. The way these will impinge on airspace management are analysed under viability, compliancy, efficiency and effectiveness headings. The implications of requirements that can be perceived to be imposed by other elements within the air transport system are considered, and the ability of airspace service providers to respond to change from these sources is postulated.

Key words: time-profile analysis, financial viability, statutory compliance, efficiency, effectiveness.

13.1 Introduction

It is hardly appropriate to treat airspace as the last element of interest, because its influence is so considerable. Historically, however, the way that air services are planned puts commercial interest in routes first, with airlines vying for market share on the busiest routes and airports and the airspace navigation service providers (ANSP) being among the last links in the operational chain of activity to be considered. If they cannot cope with the demand that is being requested, although reallocation of services has become an accepted procedure to meet runway capacity limitations, the refusal to handle services on the grounds that there is inadequate airspace available has not been widely accepted. One reason why is simple: whenever there has been a pending airspace capacity issue, the ANSPs have invariably manufactured a solution. The release of airspace over the North Atlantic through the adoption of MNPS criteria has been discussed in Chapter 8, and there are many similar, seemingly less significant but certainly crucial, system developments that have warded off the effects of an impending airspace capacity crisis.

Clearly, however, if the systemic views used throughout this book are correct, airspace issues are of the utmost importance because airspace

management deals with the space available in the atmosphere, and there is either enough of it or there is not. If there is not enough, there are very few ways in which extra 'airspace' can be created.

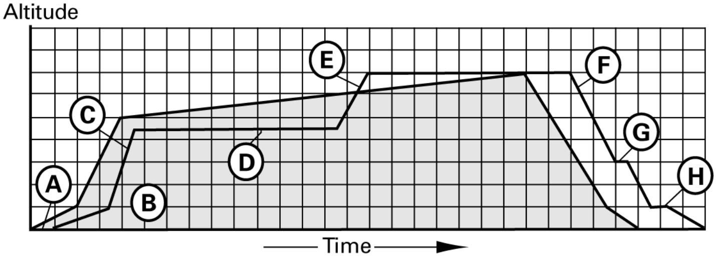
In its most simple forms, ATCs, have not so much threatened or negated any of that, but they do threaten to erase a lot of the human element. These are communication, navigation and surveillance (CNS) system changes that are inevitable. In the ATC community it is the gradual erosion of human interaction, especially within radio communications and increasingly through the use of computer-based decision-making tools, that has begun to concern many. It is a 'gut-feel' held widely in the ranks of aircrew and air-traffickers that as the ATC-centred 'request, assess and control' process is dehumanised, computer-based decision-making will lack the flexibility to achieve the anticipated standards of service across all flight regimes.

Pause to consider what airspace management is about. It is a profession that sets out to ensure that each aircraft, in the region of airspace that is under their direct control, is allocated a block of airspace, roughly based upon its position and its intentions, and within which the aircraft's occupants can feel assured that no other air vehicle or hazard will intrude. When there is only one aircraft to consider, the task is non-existent. When there are two or more aircraft, the controller has to apply separation standards, which imply a minimum separation that is legislatively defined. In fact, the separation criteria, because they are minima, are not applied *de rigeur*, but with as much leeway as possible. When there are only two aircraft, the separation minima might be irrelevant, but as the number of aircraft under simultaneous control rises, separation issues become manifold. It is not a simple square or cube term, because airspace configuration plays a big part in the procedures in use. Any controller who is forced to respect the minimum possible separation in all circumstances is in a highly stressful situation, and only one aspect of ATC has been forced to accept this as a frequently applied separation principle, and that is the approach control at busy airports.

The capacity of a runway in terms of the number of arrivals (and departures) that it can handle in a given period of time is often exceeded by the demand generated by the operators, and thus the approach operation (which is more critical in terms of separation than departure) can be working at full capacity for extended periods. This situation is threatening to be extended, from the approach sequencing process into the whole descent phase of operations, which cannot be divorced from departure phases, as the two streams have to co-exist in the airspace around any airport. It could then extend into the en route airspace, where the flow from the many airports, all increasingly busy, is threatening to create demand that the conventional approach to control cannot absorb without unacceptable risk.

The attribute that is being managed most aggressively in this debate is flight delay. It is rude to say that no one really knows what is an 'ATC delay' and what is not in this category, but it is a fact. There are many organisations who measure delay, most usually by looking at scheduled times, which is a mockery when airlines set improbable block times so that they have 'slack' in the schedule, since delays cannot be absorbed in fast airport turnrounds. An example is a flight scheduled to take 80 minutes, with a scheduled departure time (SDT) of 0745. Its scheduled arrival time (STA) is, therefore, 0905. If it departs at 0754, a 9-minute delay can be assumed, but perhaps the delay was due to ATC holding the aircraft with passengers on board and the doors closed, or was due to baggage handling needing more time to load baggage. Perhaps the baggage handlers had been delayed in starting their job because fuelling was in progress when they had rolled up at the aircraft. These issues apart, say the aircraft nominal flight time is 71 minutes, then from their 0754 departure the aircrew can expect to arrive at 0905, exactly on time. On a particular day they might be fortunate enough to have a tailwind that will deliver them 5 minutes early, but then an en route conflict will perhaps rob them of a preferred cruise level and the lower cruising altitude might mean a lower ground speed, which will absorb 2 minutes, and on approach ATC sequencing might inject a further 3-minute delay. Instead of arriving at the possible time of 0859, the aircraft again arrives at 0905, which is 'on-time.' A vital passenger service quality objective has been met, but what delays are recorded? Frankly, there is no way of knowing. No amount of information technology will be able to circumvent the 'dodges' that sharp-witted operatives can use to bias the entry and interpretation of information.

Although it is not on their acknowledged job specifications, ATC management teams have been trying to fathom this debate almost since the first ATC service was launched. They do accept responsibility for the timely operation of a service, and as demand levels have crept towards capacity ceilings, it has become customary for procedures to require an operator to book a 'slot' or to request a 'slot', with a given amount of notice. The ATC service accepts responsibility to handle the service at an agreed time (or any other time, provided reasonable effort has been taken to operate as near the 'slot' time as possible) and will accept that if the aircraft is able to start its journey on time, any in-flight delay, other than delays directly created by weather-related circumstances or introduced by the crew in order to meet operational constraints, will be attributable to some ATC service operation. The start and end points of responsibility can be the time at which the aircraft leaves its departure parking stand and the time at which it reaches the parking stand at its destination. In some cases, usually where airfields are small and the ground-operations function is not a significant capacity issue, take-off and landing times only are monitored.



13.1 ATC delays. The line enclosing the shaded area is the optimum operation, with uninterrupted climb and descent and cruise-climb. The accompanying line shows how a flight can be affected by non-optimal clearances from ATC. These are: A, delayed start-up; B, non-optimal departure clearance; C, non-optimal climb; D, held at low cruise altitude; E, allowed to conduct 'step-climb'; F, late descent clearance; G, interrupted descent; H, hold before landing.

The plot in Fig. 13.1 is an attempt to show delays in a diagrammatic sense. It is a time versus altitude plot (an unusual combination), but it is time that is the delay variable, and non-optimal altitude flight conditions, especially for a flight with a long cruise phase, are often the source of the most significant operational dilemmas for aircrews. A brief review of the delay circumstances shown, with some reflection on the sources of what creates concern and that link back to the other elements of the air transport system, provides a starting point for looking at concerns about change, as it generates a framework within which the rest of the debate on these issues will be hung.

A. *Delayed start-up*: a passenger service quality attribute. All operators like to see an on-time departure shown on public displays. It is also an airline efficiency parameter as it assures the operator that the aircraft can meet its utilisation target.
B. *Non-optimal departure clearance*: a vital fuel-usage and potentially a noise issue. The environmental impact of non-optimal departures, while considerable, are equivalently associated with excessive fuel burn, which increases costs and can erode reserves.
C. *Non-optimal climb*. This is also a great fuel-usage issue. In long-haul operations the aircraft is heavy and will climb relatively slowly, so any non-optimal climb will lead to delay and to excessive fuel burn. The environmental pollution impact is greater, but noise is less of a problem once the aircraft is into the climb. In short-haul operations, this is a very significant phase, for if the cruise phase is short, this will be the flight phase that uses most fuel.
D. *Held at low cruise altitude*. Flying long-haul the aircraft may be very heavy and unable to reach its maximum cruise altitude at the top of

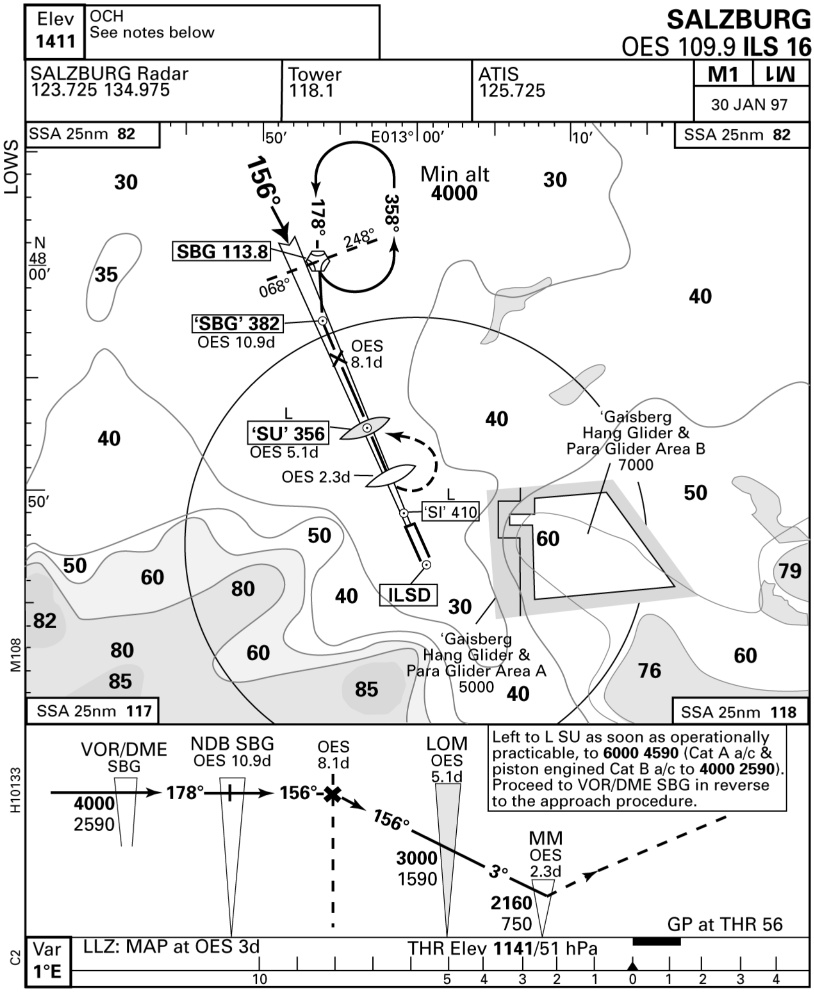
climb. Ideally, it would cruise-climb (letting the aircraft climb gradually as fuel is used and aircraft mass diminishes), but as ATC separation invariably requires aircraft to cruise at constant levels, this is not possible and the crew will have to fly with an increasingly non-optimal fuel burn. This is bad in almost every respect. The aircraft could cruise more efficiently at higher altitude, it would have less of an environmental impact and it would be less likely that the crew would have to look at dwindling fuel data and make unpalatable safety decisions.

E. *Allowed to conduct 'step-climb'*. This is actually 'good news', as it allows the aircraft to transfer to a more efficient cruise condition. This is a silver cloud with a dark lining, however, as the fuel-usage so far has been excessive and in climbing the aircraft uses even more fuel. A step-climb is only of value if it delivers an aircraft into more optimal cruise conditions in sufficient time for the benefit throughout the remaining flight phase to outweigh the penalties already absorbed.

F. *Late descent clearance*. This is a rarely encountered situation in long-haul service operations, but it is not uncommon in short-haul. The aircraft is now in a position whereby, to keep to schedule, the crew has to descend rapidly. This can be a safety issue in terms of terrain avoidance, but ATC procedures will impose constraints to provide protection. Inadvertent penetration of flight level minima is not unheard of, however, when crews are unfamiliar with a region, or even if they are familiar and their concentration is elsewhere – say on fuel burn. In any case, even if contained, the operational efficiency effect is substantial and the environment impact can be regarded as compromised.

G. *Interrupted descent*. This is a corollary to non-optimal climb, as it is likely that this will be the downside of improving the departure service at an airport where the aircraft is now arriving. A lot of aircraft can slow, or descend faster, but the ability to do both is very limited. In some aircraft types crews know not to try to do both together. The performance limitations of the aircraft can lead to a situation which the controller can only solve by imposing delay, and the most common way is by using the delay method introduced next, and finally.

H. *Hold before landing*. An aircraft that arrives in the vicinity of an airport at too high an altitude, or with inadequate separation from other aircraft in the approach stream that is being joined, has to be given a flight profile that will allow the flight conditions to be altered. The 'holding pattern' is a procedure from early days that involves arriving over a designated point and flying a 'racetrack' orbit, descending in stages, with ATC clearance, and leaving the oft-called 'stack' when ATC can introduce the aircraft into the approach stream. Figure 13.2



13.2 An aerodrome approach plate showing a holding pattern (extract from Thales charts – not up to date).

shows an extract from a typical aerodrome approach chart used by aircrew, including details of the ATC limitations they have to observe. Clearly visible on the chart is the racetrack-shaped holding pattern.

13.1.1 The transition from air traffic control to air traffic management

Gently, over a couple of decades, the well-known phrase air traffic control, usually spoken as a three-letter title (A-T-C), has been massaged in the

international forum into air traffic management, likewise spoken as A-T-M. Comments abound throughout aviation that the change of phrase implies more choice for the customer, whereas authorities (many are governmental departments) are demanding that additional equipment is being declared as mandatory for operations in all airspace. This sets a no-choice and costly scenario that reeks of over-control. It is difficult to get a consensus on what is happening.

The development of ATC has been shown (Chapter 8) to have been substantial, and in terms of what the non-involved observer will see it has been an almost invisible change. Anyone can tune into aviation radio frequencies nowadays, as they have done for decades, and listen to ATC 'chatter' that has the same characteristics as it had a long time ago. The changes outlined in the earlier chapter, in communications, navigation and surveillance (CNS) system components, have all contributed to the controllers having more information available to make their decisions. Subtly the mode of operation has changed, therefore allowing more complex situations that arise in more congested airspace to be interpreted and controlled with confidence. It is because the demand is rising still that the separation minima are more and more a constraint on the actual operation. It has to be said that the controlled airspace around busy commercial centres has increased considerably, and to the general aviation community almost inexorably. They are that part of the aviation community that is at the vanguard of attacking airspace authorities for now imposing more stringent minimum equipment specifications on them. This is not a debate that can be included in full here, but it is important that acceptance is signalled that the encroachment of controlled airspace into the uncontrolled airspace where general aviation is practised is minimised. The opportunity to 'give back' some airspace would be nice, but that seems very unlikely to happen.

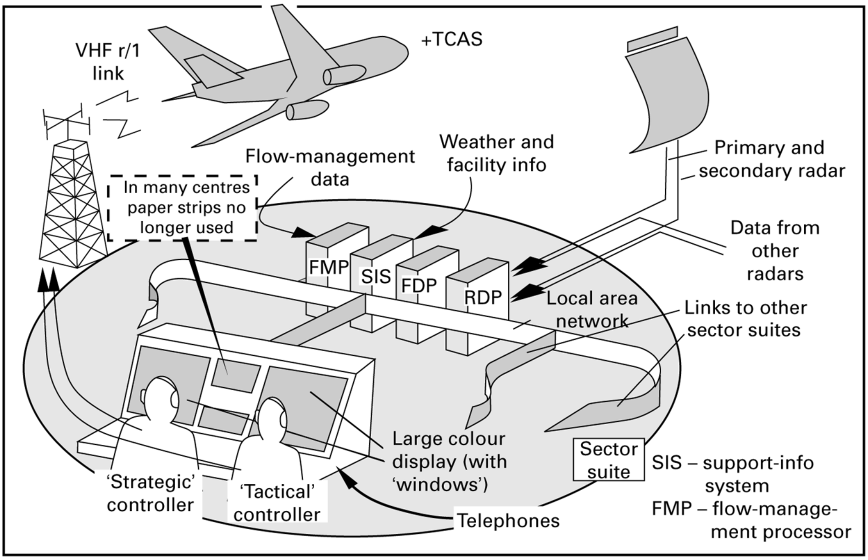
In the future, airport-based ATC will see no fundamental change. If traffic levels continue to rise as predicted, larger proportions of airports will work at capacity, or be close to capacity for long periods of the day. The runway-based approach and departure operations will remain substantially unchanged, albeit efficiency will be assisted by airport investment into more rapid-exit taxiways and other physical infrastructure developments that minimise the runway occupancy time of individual movements. The ease of access to more real-time data will certainly affect the way that controllers develop their personal schemes for making best use of each patch they police, and could lead to some improvements in service qualities, but these will be relatively piecemeal and may be so small that it will be a function of experience and confidence, and simply irrelevant to capacity.

In the terminal areas that surround airports and in en route airspace, the changes will be considerable. Indeed, they may be so profound that it may

no longer be possible to listen to operational r/t. The communications analogue-to-digital transition seems certain to lead to less and less r/t interaction, with more digital messages being exchanged. The r/t will not become irrelevant, although it may be redundant – in normal operations at least. In abnormal operations the r/t is always likely to be the most preferred form of communication, because crews and ATC staff prefer a contact mechanism where the nuances of speech, in tone and inflection, as well as flexibility of phrase, are still regarded as vital to keeping emergency situations under control.

The main technical contributors (all defined and described in Chapter 4) to future ATM operations will be:

- *Mode S data-link*. The data-link will be like a very formalised r/t, where standard messages will be able to travel either up or down between the aircraft and the ATC unit that operates the interrogator ground station (which is still likely to be called SSR). In addition to allowing levels to be displayed on the ground radar display, this system will allow the ATC-operated ground computer(s) and the FMS in interrogated aircraft to exchange data.
- *ADS (especially ADS-B)*. This regularly polled unit will convey information to satellites, which then have the capability to convey the data to a ground station. Messages will be polled every few seconds and will collect aircraft call-sign, position, flight vector and additional data. It will replace primary radar and introduce the equivalent of a highly accurate primary radar to hitherto inaccessible locations, such as over oceans.
- *TCAS*. This is already in use and depends on SSR responses. TCAS could evolve to be ADS-related, and if it retains its SSR-based functionality it will have sufficient redundancy to be able to assure survival in some currently hazardous failure cases.
- *TAWS*. This is the latest development to come from the GPWS stable and will, independent of the crew, monitor relative position to terrain, issue warnings and may even be programmed to initiate avoiding action.
- *FMS*. This is set to become the central mission computer for the aircraft. In addition to data from its internal databases (routes, navaids, airport arrival and departure routes, aircraft performance) and on-board sensors (fuel, airspeed, ground speed, etc.) it will now receive data, via Mode S, from the ATC ground computer(s).
- *ATC computers*. The way that the well-established radar-data processing (RDP) and flight-data processing (FDP) elements of the 'automated' ATC system evolve and are integrated with real-time serviceability and weather data will make the computers as 'aware' of the situation in the airspace as the actual controller. This has been underway since 1990, so



13.3 Future ATC system configuration.

the concept is not fanciful, but it is the implications, and the way they will be exploited, that can introduce dramatic change. This is likely to influence all elements of the air transport system.

The evolution in ATC systems, described in Chapter 8, shows what components are anticipated to comprise the system of the future. To illustrate the major components and to show their relationships, Fig. 8.8 used in Chapter 8 is shown again (Fig. 13.3).

The four computer units (likely to be 'functions' within an integrated computer system – the architecture shown is illustrative only) are:

- *FDP (flight-data processor)*. This is used where airline-furnished flight plans providing data on date, time and route intentions – probably updated near to the date of operation to reflect aircraft type, etc. – are collected many months in advance, when IATA-facilitated airport slot coordination has been completed, and the regional authority (e.g. the Central Flow Management Unit (CFMU) at Eurocontrol in Europe or the equivalent cell within the FAA in the USA) has approved the proposed operations. There will be space reserved within the airspace for last-minute operations, such as business and executive flights, and military transport operations that use controlled airspace.
- *RDP (radar-data processor)*. Like the RDP in current-generation systems this will collect and combine data from various radar sources. The 'radar sources' are less likely to be primary radar. They will be

secondary surveillance radar (SSR) and Mode S compatible. Thus they will also be a communications data-link between the aircraft and the ground. Primary radar is no longer expected to be regarded as an essential surveillance aid, although it will be used by weather services to detect and track meteorological phenomena, and this information will arrive via the SIS (see the next paragraph). The processing unit, as many do already, will include conflict-detection probe software, so that if real-time tracks are predicted to reach within critical distances of separation minima the system will present a warning to the controller. This is a predictive tool, designed to give considerable warning (about 10 minutes). Getting the system to do that without creating a large (and unacceptable) frequency of false warnings is what has been researched and developed over some 40 years of related studies. Future systems will also include conflict resolution tools, which will allow the controller to choose one of a menu of resolution options. These are under development and in some cases on trial already. It is envisaged that a conflict-resolution system will exchange information with affected aircraft FMS installations and in an extreme scenario will upload the resolution to the aircraft, for the FMS to direct the AFCS to take appropriate avoiding action. This is science fact, not science fiction, and granted international acceptance it could be in service relatively soon.
- *SIS (support information system)*. This is a generic term that largely refers to weather information, but can also capture Notams and other operational information that arise at short notice. The idea is to replace the age-old method of clipping printed or scribbled reports on a board adjacent to the controller's display and to integrate the information, by combining it on the main display or by providing an ergonomically moulded interface that will either lead the user to information or recognise its applicability and present it on screen. Getting such interfaces right has, again, been the subject of many research programmes. Interestingly, they tend to be technology-led, and the way ahead has often been achieved most successfully when the ergonomic process requirement has been expressed in terms that technologists can interpret and respond to. The nuances of the human–machine interface (HMI) are still being tested more thoroughly in ATC system development (and on airliner flight deck research projects) than in any other modern operational application.
- *FMP (flow-management processor)*. This is assumed to be local in the diagram, but it could be a link to a remote unit. It signifies that there is a world of difference between the long time-horizon slot-coordination planning conducted to create the FDP database and the way that traffic presents itself to the system on the day of operation. The reconciliation of these differences can be very significant, and an example that

illustrates the complexity of the issues involved is to consider the arrival at a European airport of aircraft from intercontinental destinations. This is cited as an example because anyone who lives near a major international airport in Europe will know that around 0600–0800 local time in the morning large long-range aircraft arrive from east and west, disgorging passengers, who then often connect with other flights. Meanwhile, there are flights arriving from closer range which have been assured a 'slot', so it is essential that their need for a slot (say, at 0645) is respected, even if they do not start their short-haul operation until 0600. It could easily be swallowed by a bunch of long-haul aircraft that are arriving earlier or later than was planned, possibly due to wind or operational time variations. Real-time flow management is handled by coordinators, who if they do their job well can get information on slot availability to long-haul crews when they are many hours still from their destination. Introducing a 10-minute delay that can be absorbed over 5 hours requires a 2-minute per hour rate of absorption, and is tantamount to asking a crew to fly at, say, 465 knots TAS rather than 480 knots. This is achievable with very little impact on fuel usage. It requires, however, that means of communicating and using this information are integrated into the ATC system and the aircraft. This is a prime example of an air traffic management (ATM) system function.

The way such a capability can be achieved is by having a global data-link system. This can be integrated into the components of the autonomous dependent surveillance (ADS) or achieved through cooperative use of Mode S systems – the likelihood is that whichever is used will be a local preference. Where both are available, one will be a redundant back-up to the other.

First, they supply real-time information on the precise position of all cooperating aircraft.

Second, they allow the flow-management function to interrogate the aircraft's on-board flight management system (FMS) and to be informed of the impact of requested flight plan changes.

Third, the ground-based system adjusts the anticipated flight times at strategic waypoints of all aircraft and assesses the combined impact. It can be tuned to optimise the degree to which extra fuel usage is required against commercial reliance on timely operation of a service, but all the time adjusting traffic so that the workload on the controller will be acceptable and the overall capacity-demand and delay compromise is implemented in an acceptable manner. All this can be happening while a controller sleeps at home and be involving aircraft that are a quarter globe-span away, as well as aircraft that are having their wheels and tyres checked in hangars a thousand miles away.

Finally, the ATM system flashes messages to airborne aircraft and

revised release or flight-time instructions for storage in ATC unit computer databases worldwide, for operatives to act upon them. It will become commonplace for a captain inbound to Europe from the Far East to receive a message while over India that will propose a revised approach time at their destination and suggest a reduction in cruise speed. If the captain accepts that proposal, the signal confirming it will be read by the aircraft's on-board FMS, and the autothrottles will reset the cruise speed. Passengers sleep, controllers sleep, flow-management computers work and captains remain in command and well informed of their flight progress.

The way that ATC is evolving into an ATM service is stretching the horizons over which decisions are made, physically and across time, far beyond where the old-time ATC horizons were laid. A controller arriving to commence a watch at 0600 has no idea about how much their workload has been moderated by computers acting out the requests of flow coordinators over preceding hours.

This is such an invisible and high-technology development that it has required considerable international debate and development, and the process has taken the lifetime of many of the people who are now watching this system come into its own, just as they retire. However, for the airspace service provider in each state worldwide the old question is still the most important to them. How do they pay for it? By now the tone of the answer should be familiar – they have to justify it through the relationship of costs to service attributes. It is via the four headings used to define such matters in previous chapters that they are introduced again.

13.2 Financial viability

Most of the preliminary work on systems with ATM applicability has been on-going from the 1960s, when the scientists who developed the first automated ATC systems saw what potential there was for further development. They did not know how information would be conveyed about, but some were far-sighted enough to appreciate that global communication limitations would be beaten by satellite-based systems. These were largely government scientists, and the expenditure on relevant research was centred, probably 90% of all research worldwide, in the USA. In Europe there were cells of appropriate expertise, but the main integrating interest was through the military, who tend to have a greater need to cooperate than US counterparts, given that Europe does not have such 'free' areas over landmass or water as the continental USA. Eventually expertise has tended to gravitate into the USA, because European nations have been absorbed with solving their own airspace crises and have been slow to

collaborate. In the USA some 20 air traffic control centres have been equivalently equipped, and throughout developments spanning the years since 1945 the integration between them was almost natural. In Europe the interface tale was different, with computers programmed in different ways. Eventually Eurocontrol, with EU support (and thus with national governmental funding), drove through a common interface strategy that has been important throughout the 1990s and after, to get all European state ATC computers able to exchange data automatically.

Essentially, the state has accepted the cost of research and capital investment throughout the world and the service providers – all national airspace organisations – have sought to run their daily operations with justifiable expenditure and revenue accounts to show that they are viable operating businesses. In the USA this is FAA-administered and is non-contentious compared with Europe, where each nation has its own level of costs. Eurocontrol has again taken the role of arbiter, and had developed a way of expressing charges (based on aircraft mass and distance covered per flight) and a charges collection service. Thus airlines do not get bombarded by demands for air-navigation service payments from every nation, every month, but they get one bill for European services. Eurocontrol aggregates their payments and re-distributes fee income to the appropriate authorities. By the same token this saves every state having to invoice every airline. Note that airport charges are quite separate, and airlines settle their own accounts for movements and handling with the airports directly.

As the belief grew that market forces should shape the financial landscape in civil aviation, national airlines were privatised and airports moved out of local or national government ownership (all tending to go that way, but these are not processes that are anywhere near complete yet), so airspace service providers came under equivalent scrutiny. The 'privatisation' of airspace service providers has been handled with appropriate care, given that the investment in research and capital equipment is great and the technical risk associated with achieving sound implementation is considerable. Furthermore, the operational risk is massive. This could also be said of running an airline, but an ATC system failure can involve more than one aircraft and it could involve innocent third parties on an enormous scale. Addressing a fundamental problem in the systems could be monumentally expensive, especially if the cost of reduced service quality – perhaps capacity capping that will affect the viability of almost all airlines – is taken into account.

The inevitable outcome has been to progress with 'partial privatisation' of the businesses, whereby they are now registered companies and have to justify all their expenditure and accept some liberal scrutiny of their charges. The state is expected to foot the bill for research, which begs the question of whether, through such an arrangement, the researchers will be adequately in

touch with the operators. Meanwhile, state-run research organisations are often separately privatised.

When an ATC system upgrade is performed nowadays, the cost is based on the value of a commercial contract with the supplier (often a consortium) and the money is raised largely through commercial markets. Some government subsidy is allowed in some states. The cost of that loan becomes a part of the airspace service provider's operating costs and will be recouped from daily revenue. Hence financial risk is minimised, but the cost of implementation is borne through a very transparent commercial process, so that airlines – the main direct users of the service – can be assured that the costs they face are justifiable and managed appropriately.

13.3 Statutory compliance

The basic ATC functions have already been described in sufficient detail for a cursory mention of their obligation to ensure safety to suffice. They agree to do this in a way that is as fair and accountable as possible. Therefore, if a dozen aircraft are approaching an airport and five are from airlines based there with the remainder being visitors, the system handles each as an object, whose location, vector and capability will determine the order in which they are sequenced to land. Delays will therefore be shared, and while an airline's delay record might vary day-to-day, the overall level of delay will be a measure of how well the service copes with demand.

The collection and analysis of ATC delay statistics is a fraught business, as the datum used by various agencies – some of which might have a vested interest in filtering the source data – is never precisely defined. It is, for example, difficult to attribute the whole of a delay to ATC, or weather, or technical causes. Overall, it is believed that if the average delay over a traffic sample is less than 3 minutes, the delay performance is acceptable. Where busy airport systems are being studied, there is often a modelling procedure that is used to predict delay, and the incidence of delay is then correlated to the modelled data as a validation process.

Like airlines and airports, ATC systems have a well-established safety management culture and will maintain service at predetermined levels over guaranteed periods of time. This can mean that as equipment ages and failures occur, the delay that is apportioned into an affected traffic sample will affect the average delay time, so safety and service quality are more closely associated in the airspace management sector than in most others.

When a service level is defined, the airspace service provider is usually tied to an internationally agreed implementation, such as MNPS or RVSM, or is related to FANS, so there is little leeway to be innovative in this safety-conscious and very well-regulated area.

13.4 Efficiency

As well as gathering information on delay, data are accumulated from radar track files, etc. One more fundamental but difficult to monitor (in real-time) service attribute is the distance between aircraft pairs, at their closest point, compared with the separation standards. In true engineering terms the system would be 100% efficient if all aircraft passed at the separation minima. This would be absurd, however, and the expectation is a distribution that respects the minima and has an average minimum separation value considerably greater than the minimum – perhaps in excess of 5 or 6 times. Since air traffic systems have incorporated flow-control processes (allocating 'slots' to aircraft at their point of departure) and as navigation systems have improved in accuracy, controllers have been able to vector aircraft with greater confidence that they will fly a predictable trajectory. As the dispersion of separation minima has reduced, efficiency has improved, albeit almost without being noticeable.

There is every expectation that the average separation will reduce gradually in the future, as higher confidence in the quality of information allows more opportunity to work closer to the minima. While this represents an increase in efficiency, it is also a threat to safety, as there is less opportunity to correct errors. There are more safety monitors with the ground-based conflict detection and airborne TCAS systems basically monitoring the same situation, but from the perspective of the respective individuals.

Some failures do get through the system, and these are the ones that matter most. Once seen, they need to be remedied, to ensure that the probability of seeing the same failure again is virtually eliminated. It is often difficult to categorise the kind of failures that occur through inadvertent mis-use, and while education and training is a part of the mitigation process, these are the silent enemies of the most safety-conscious individuals.

13.5 Effectiveness

Everything that can be assessed under this heading, within the by now familiar context of service quality attributes, seems to have been mentioned in passing, because the relationships with the other attributes are so intractably mixed in air traffic processes.

The capacity-demand and delay relationship is the most fundamental effectiveness indicator. The plot shown in Fig. 8.5 has an arrow that indicates how reducing the dispersion in a traffic sample can improve the demand level that can be handled in a fixed capacity system and respecting a given delay level. Any trade-off in this area is an effectiveness change.

If air traffic systems were internationally homogeneous, that kind of

mathematically justified expression would be fine, but the great disparity between systems imposes boundaries on attainable performance. An aircraft that is about to leave its stand and requests a slot clearance may be about to leave on a journey that will cause it to pass through more than a dozen national airspace regions. Getting a slot promised for the aircraft is clearly a logistical nightmare that can require a diplomatic as well as professional approach.

The days when ‘first come, first served’ was a guarantee are gone. Fair operations are assured through operations that increasingly are subservient to technical mastery, with a massive hit on capability if the system has to fall into the ‘manual’ mode. (The old ‘procedural’ is the ultimate floor, which few airspace operations can tolerate being forced to nowadays.) When air traffic management is viewed as a service, the temptation is to look at it through the eyes of the user. Offering best service to the customer is the primary goal. It is worth adding, however, that the eyes of the implementer are as important. The day does not loom as a date on a calendar yet, but the fear among many ATC staff – especially in the en route sector – is that it is palpably close, when they will be system operators whose involvement will be so far removed from the tactical and strategic decision-making that they will become ‘passengers’. The situation is not dissimilar to that experienced with all-electronic flight decks, and if ‘effectiveness’ is to be maintained in the air traffic management profession, it will be through reconciling user effectiveness objectives, while keeping the operative procedures at a level that maintains their awareness of the situation. Of all the development areas that are seen in civil aviation, this is perhaps the most challenging of all.

14

Systemic processes: the way ahead

Abstract: This concluding chapter reflects on how incumbents often fail to orientate themselves towards systems thinking. It accepts that many individuals are drawn towards their most familiar perspectives, and to combat this a strategy that can introduce detachment is introduced. The technique outlined evolved within teaching and orientated interest under the viability, compliancy, efficiency and effectiveness headings already used. Implementation that will encourage learning and inquisitiveness, that encapsulates skills and that layers understanding is discussed. Five potential future scenarios are considered, inviting equivalent reader reflection. The chapter shows ways in which the elements of the air transport system can be structured for study, for research and for debate.

Key words: shift in the safety paradigm, shift in environmental impact, the case for larger aircraft, hub versus direct service options, the threat of more attractive modes of transport.

14.1 Introduction

The conclusions that can be drawn from looking at the air transport scene from a 'systems' perspective are manifold, but because it is natural to be drawn towards their most familiar perspectives, most observers find that it is difficult to detach themselves enough to keep their considerations broad enough, and across the many disciplines. That has been a major reason why the chapters have addressed elements and cross-referenced to other elements within a context that should be familiar to specialists. At some point individuals have to set out on their own.

In teaching, young students are not blinkered by experience, yet incumbent managers often, but not always, can be servants to their genuinely carried responsibilities – often so much so that even senior managers will wonder whether they are right to complain to, albeit quietly, as much as they compliment rising 'young turks'. It has been on the shoulders of managers who have wondered if there is a way to address such

maladies that the ‘four principles’ concept, which has been used to structure the wide range of debate in this book, has grown. Without such insights from the real world, it is doubtful that an atmosphere can be created that is good for education, for developing skills and for laying the understanding that will serve people well as they pass from the academic to the real world. Good education will establish goals in all of these three areas, but learning is not just enough.

When it comes to passing this knowledge on to the longer-established incumbents of air transport businesses the dilemma is how to ‘teach’ those who are more than competent to hold court in any classroom. In this final chapter the processes that have been most successful in finding a route towards better learning environments for a wider range of individuals who are within, or associated with, or just keen to explore the world of air transport are discussed. The starting point is a personally orientated account, which opens the ‘systemic’ views that then draw together the many facets of the chapters.

14.2 Air transport education and research

Teaching air transport topics is often undertaken by two distinct groupings, either ex-specialists or individuals whose knowledge is developed from study rather than practice. Put them together and they have synergies that are invaluable, so a pre-standing requirement is that any learning must be accessible to people of all persuasions. This can be extended to encompass – ideally – all age groups, mixed-gender audiences and people of all creeds and nationalities. As aviation appeals across such a broad spectrum, this is essentially a fair, albeit ambitious, remit.

In the past it was regarded as fine to write a book in which knowledge was distilled, and the reader was able to pick their way through the pages. The journey, as many will know (and as readers here may have done), can be far from a simple read from front to back cover. There is a temptation to steal a glance at the ‘sections’ of greatest personal interest. Some books, viewed this way, will simply re-visit familiar ground, but some books do it so much better that they will stimulate the reader to address other areas. If the author has done a good job, the book ends up being read from cover to cover. If it becomes a firm favourite, it has been especially successful. Most people have a small number of books on which they will heap such honour.

In recent decades it has been air transport itself that has opened the opportunity to advertise a learning programme and to attract learners from all over the globe. Speakers can also jet-in, offering the prospect of learning experiences that can address even more ambitious ranges of topics. Few aviation professionals worldwide can recall a week when they do not receive a summons to a prestigiously titled event. However, courses and conferences

are valuable only occasionally for introducing new material directly. Individuals often gain more from their out-of-session experiences at such events. The idea of many seminars is to develop the out-of-session experience to become the core experience, and the most successful are often those where the delegates know each other well.

In the mid-1980s, with information technology beginning to seep into every nook and cranny of civil aviation and the desk-top PC was suddenly apparent, new teaching methods became possible. This author, among many others, was keen at the time to try developing computer-based training (CBT). A major driver from the academic seat occupied at the time – that happened to overlook an airfield apron – was that while aeronautical students would be given testing objectives that would hone their skills in materials, systems and aerodynamic laboratories (some of which were very expensive to operate), the air transport students could not be let loose to manage a fleet of airliners (which are even more expensive to operate). Having an apron so close, however, made the idea very appealing.

What followed was an unprecedented journey. The text of others – at that time the works of academics such as Taneja and de Neuville – and meetings with practitioners such as J.E.D. Williams and Ken Wilkinson (respectively retired from Britannia and British Airways) were personal sources of inspiration. Simple computer programs evolved that would allow a user to investigate how fares would influence the demand for a service. A two-tier fare structure was postulated and the mathematics was challenging; a revelation was that often the crudest concepts carried the best learning results. The initial program became embedded into a series of programs, and by 1987 there was a suite that would allow any student to be given the opportunity 'to create the airline of their dreams; because there were 600 airports and almost 40 aircraft types modelled in the system. While this was a process that met the primary aim, where individuals could apply their own knowledge and demonstrate new-found skills, it was not as intense as the laboratory experience of student engineers. The hammer blow of failure was absent. It was a solitary experience for each individual, with so little interaction that many played the suite like a 'game'. Tutor support to tease out the best of the learning value proved to be an intense and difficult task to fulfil.

The fact was that personal research was being channelled into air traffic management (ATM) at the time, which was a million miles away – or so it seemed, in reality (but it was not subliminally) – from the fundamental teaching syllabi. Indeed, one issue that weighed heavily on the mind at the time was that all the ATM teams consulted, or met at conferences, were steeped in the technological debate. There was clear evidence that airspace capacity was a problem that had the power to draw the whole of the air transport business to its knees, and the overwhelming opinion was that technology was the key that would unlock the door. It was an intriguing

time, within which there were many great debates, but the route map that would link the diversity of views was slow to evolve.

During this period the research debates encouraged inquiring comment in open class sessions, with access to a wide audience of individuals that ranged from novices to veterans in the business (students and aviation business/organisation managers). They were asked to volunteer how they would define the objectives of a board of directors. No matter which element of the business they represented, or vied to enter, the outcomes could always be considered against the four principles that have been discussed with regard to each element.

They recognised that:

1. *Financial viability* was essential first of all.
2. They invariably conceded that *statutory compliance* was as essential, but ranked second, on the grounds that overzealous regulation would lead to the decision to discontinue operations, starting with the least viable sectors and progressing ultimately to business closure. They all had caveats to add that have been encapsulated under the headings of efficiency and effectiveness.
3. *Efficiency* indicators were found to be often technically dominated, in that the efficiency of a product or device is generally a function of the technology within it, or that is used to manage it (examples being aircraft in the case of a device and the sale of seats using a yield management system in the case of a product). There can also be some commercial perspectives, and the marketing of a 'brand' product is certainly a difficult-to-measure but valuable efficiency aspect. This is one example within this regime that links into the final sector.
4. *Effectiveness* was a term that could encapsulate all of the customer service perspectives. 'Customer service' perspectives are valuable indicators of the healthiness of a business case. When civil aviation was still in its chrysalis it was a rather high-brow mode of transport, but gradually it opened its appeal to a wider range of users. Nowadays it is a service for all-comers, and there are ranges of customer-satisfaction criteria to reconcile. The complexity level of effectiveness aspects have risen with time.

Debating these issues revealed how often the view of senior managers was that the creeping complexity was what made life in the business not just challenging but more stressful. Ultimately it challenged the desire of the best-informed and most experienced to take retirement. Legacy will be lost if this happens without some mechanisms being activated that will reconcile the sides of such an ageism divide. It was some time before appreciation grew that the strength of this argument was coming from young and old alike, and every corner of the industry.

Several conspirators were hooked on to ‘systems thinking’. Given that the experience of building a model of the airline business had revealed no common ground with the modelling concepts that were used in the engineering laboratories, there was some personal scepticism about the approach. It is intriguing to look back on a wide range of people who tried to trigger this line of thought.

The greatest difficulty that most people have with ‘systems engineering’ is that it is *not* engineering. The book has deliberately incorporated ‘system’ in its title, because the views it promotes are at the heart of ‘systems engineering’. There has been reason to note that engineer is a Latin derivation of innovator, and that is what the air transport business (indeed many multi-disciplinary businesses) needs today. Calling systems thinking ‘systems engineering’, because the aim is to promote innovative thinking, is therefore perfectly reasonable. It is a word choice that does plant barriers, however. Systems engineers can be managers from any number of backgrounds. Their common attribute has to be that they will contribute to weaving a common web that will enable the integration of viewpoints across disciplines within an organisation. Importantly, and usually very challenging, is also the need to ensure that this internal web has features that are compatible with equivalent viewpoints where it interfaces with other organisation within the greater ‘system’.

These words have been written to stress that, if you find the idea of ‘systems engineering’ too abstract, or feel that it lacks sufficient order to be a recognisable discipline, the experience is not rare. This account should provide an example of how innovative thinking challenges our ability to describe complex issues in ways that will allow them to travel between minds. The learning process for this individual was that to trammel descriptions with too much ‘discipline’ limited the boundaries within which the mind could work. It was fortunate circumstances that lifted a concept that initially existed only as a set of four headings from debate to the point where they were at the crux of the subject matter of interest.

The next challenge was to discover how to combine these headings (treating them as teaching objectives) and a suitable teaching format. After a decade or so out of an academic chair (and in a ‘systemic’ environment), the return brought home that colleagues were still hide-bound by the same mental boundaries; they therefore taught a lot, tried to invent skills and, as curriculum guidelines would allow understanding to be untested, they regarded good peer reviews as adequate to pass muster. There was little to nothing that was innovative. There is a contextual point to comment on at this stage – that the decade or so out of academia had proved to be a period in history when there had been a glorious increase in administrative processes. Not without good reason, procedures had been formalised that drove tutors to express their teaching objectives and outcomes in a more

ordered fashion than hitherto. Sadly, it was treated so prescriptively by most of those it affected, that it rarely did anything to encourage innovation; indeed, a peer review, conducted by a constrained thinker, could even stifle an innovative approach. There is a stark warning in this example, that those who overindulge in formalising methodologies while they seek to clarify the direction of exploration, often impose processes that constrain outcomes. It is a dichotomy that systemic process evolution has always faced, and probably always will.

The original CBT was dusted off, and it was made compatible with a PC-based flight-simulator program (Airline Simulator 2) that could then be set up to fly any selected route. This held the promise of allowing a user to get a 'familiarisation flight' view of the operation they had planned. The usable airport database reduced from 600 to 26 and the aircraft types that could be used reduced to five. This made tutor control much more manageable, and the reduced coverage was not detrimental to the teaching aims – in fact, just the opposite. That was an invaluable experience. Intriguingly, in the event, no teaching program has yet exploited the flight simulator compatibility link, because time has always been the tutor's enemy.

Thus, in a class of 26, each individual could develop and 'run' their own airline. They still worked individually, but the modern electronic classroom was used to collect their electronically held timetables (this was now the era of e-mails). A tutor program was devised to coalesce these to create a single file that was easy to distribute and was called the 'virtual OAG', because it was in a format that mimicked the OAG publication in which all airline schedules are presented under airport names, listed in alphabetical order. This was often a huge document, which is indicative of what can be achieved when information technology is harnessed to a teaching application. Intriguingly, the academic support network that assisted in the development of this teaching system revealed that CBT was by now a virtual learning environment (VLE).

The greatest pleasure of the new implementation was that, without overt steerage, participants were being stimulated to operate in a competitive situation, which became apparent as soon as editions of the 'virtual OAG' began to flow into their e-mail inboxes. They quickly devised strategies that balanced the immediate reaction – to be aggressive and competitive – with the possibility of collaboration. The feeling of 'ownership' was all the greater for having a self-developed business. The quality of debate in tutorials, and indeed in a teaching session, was incredibly enhanced.

The next move was planned with some trepidation. The virtual OAG data were reformatted, again through a computer program, and presented as a daily demand schedule (timetable) for each airport. Now the same attendees were allocated to an airport, as the 'manager'. They received a set of schedules, but these were unique. They were not something that the tutor

had created and imposed (a task often attempted, but that had an outcome which was always, in some regard, unsatisfactory). These were schedules that had been created within the learning group and had been arrived at through applying their own skills and ultimately weaving their own path in the peer group in which they were immersed.

Each ‘airport manager’ was asked to set a contract and service quality agreement (SQA) with the ‘airline managers’ that had planned the services. This had the potential to turn a classroom into a chattering mass. It was a step, however, that carried many of its own qualities. Especially when it involved a multi-cultural group, it was a delightful ‘ice-breaker’, but also this was real ‘systems’ education, because it addressed knowledge, skills and understanding objectives within a context that had real-world-like synergies. The outcomes were still under the control of the participants, and the tutor could influence – very often, learning all the time too – but it was an influence that could be applied almost invisibly. Sometimes, individuals needed to be reassured, or calmed, and sometimes they were so aggressive with their peers that it was necessary to rein them in through planting seeds that would affect their own plans. Ripples could be created that affected a legion of decision-making outcomes elsewhere, or even calm the water, without walking into the scenario or classroom and imposing will.

Subsequently a set of airport models, including a simplified fast-time simulation of passenger flows throughout the airport passenger processing functions, was developed, which allows the extraction of information that will permit an ‘airport manager’ to illustrate to some degree the way they would justify their contractual and SQA agreements. It can go a stage further too, with the air service demand on airspace shown on a virtual radar screen by a program that can indicate congestion points. This has also been demonstrated in principle, but has not been applied within a teaching program to date.

In the space of a few days, the participants in a learning program that combines classroom sessions with periods of simulated business decision-making can carry an individual through all the elements of the air transport system. This is a business ‘simulator’, which is every bit as useful to a hopeful student or a practising manager as a flight simulator is for honing the skills and understanding of flight crews.

It is also, potentially, a research tool, in which the attributes of different strategies, applicable to airline, airport or air traffic management, can be used to create input into various stages, and whose properties can be addressed. It is a significant step to climb from a 26-place classroom based VLE to a full research simulation tool set, but it can be done. In the USA, organisations such as MIT and the Mitre Corporation, funded by government and industry, do research today that uses equivalent attribute-based simulations. In Europe the elements of such simulation

are visible, but they tend to be less well coordinated and are used largely for discipline-specific research. ATM simulation research is conducted within Eurocontrol, airports are modelled at Aachen and aircraft are modelled just about everywhere, as all academics, it seems, want a flight simulator.

The latter is not meant to be labelled as a crass observation. The flight simulators that are used in many universities nowadays have links into industrial organisations, where they can operate in conjunction. They could just as well develop business simulators that operate in conjunction, using the internet to exchange information, and with an international set organised to represent the philosophies of different nations. Their collaborative interactions would soon show where elements of the system create requirement dilemmas and would allow assessment of solutions that range from tackling deficiencies alone to studying the most effective multi-disciplinary solutions. If, for example, in some nations the balance between financial viability and environment attributes is quite different, for a period over which one of them has an agreement to steer towards the objectives of the other, the collaborative assessment of performance might help to balance effectiveness with financial viability more equitably than if each nation worked independently. Such work could also accelerate the timescale of implementation, and again be able to show long-term savings.

The biggest breakthrough in the development process described was achieved when individuals, having been set off to fulfil individual tasks, found themselves facing perturbations from decisions being made by colleagues without acknowledgement of their impact on them and emerged from the experience able to reconcile their knowledge with their skills. Industry is usually quick to recognise these qualities.

14.3 System solutions

The way that the concepts that have been described can be used in the future, to assist in finding the common wisdom that will carry systems thinking deeper into the implementation of teaching and research programmes is perhaps the greatest challenge of all. An example that illustrates the starting points that can be considered is presented next.

In Chapter 1 the first issue considered in depth was the way that demand could be served between a homogeneous set of nine destinations, set out on a regular grid. It was presented to illustrate the considerable differences that airline strategies can have on airports and the ATM system. The fact that there can be other solutions to the ones analysed can be addressed once there is a tool that can forecast demand, analyse the passenger flows, assess the attributes of interest in the domains of interest and present information that will allow decisions to be made.

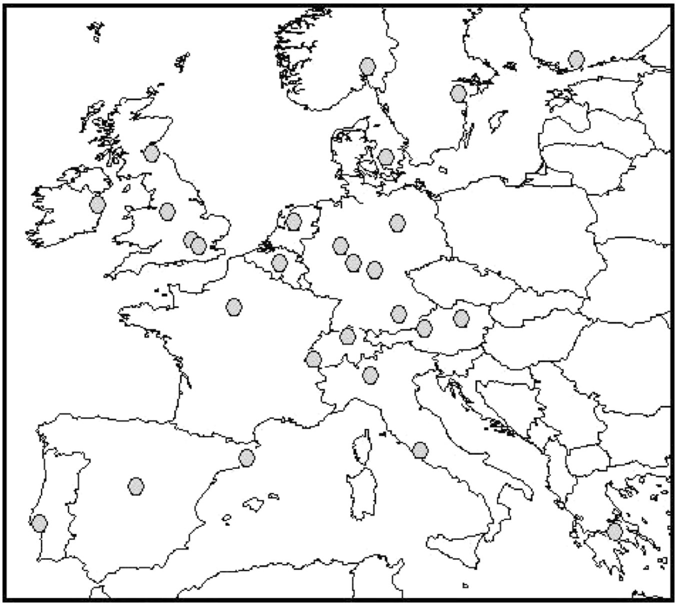
It is not so easy when airports are not so regularly scattered, when they

are numerous and have natural propensities to be better hub locations than others, and so on. The teaching system mentioned has been used in a 'research' mode to create a simple investigation of a situation that, when introduced in class, has stimulated intrigue and debate. It has involved the construction of an airline route structure with multiple (one, two or three) hubs within a real-world configuration and studied using components of the CBT program suite.

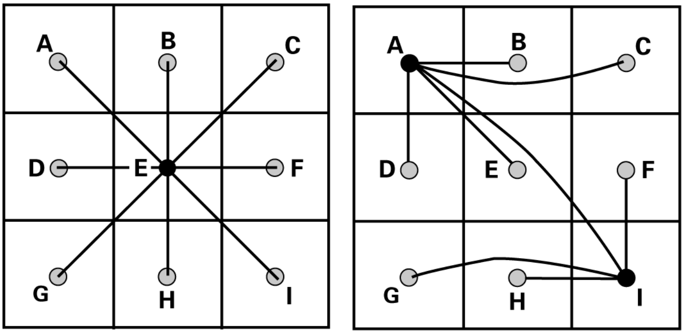
Figure 14.1 shows the 26-airport system that was available for analysis, and within this a group of individuals selected nine airports for study. The selection criterion was that the selected sites covered the main regions within Europe. Some close city-pairs were deliberately chosen so that surface-mode transport competition would have to be taken into account. The airports were (in alphabetical order) Amsterdam, Athens, Copenhagen, London, Madrid, Paris, Rome, Stockholm and Zurich.

These were allocated using London as the hub on the single-hub scenario and with London and Zurich (selected for dispersion) for the two-hub scenario (Fig. 14.2). (Four airports were allocated to London, but look closely at the map in Fig. 14.3 and try to justify why Paris was linked through London and not Zurich.)

For the three-hub London was retained and Copenhagen and Rome used as the additional hubs. Each was linked to two outstations, and the very neat (logical looking) route structure that appears on the schematic (in Fig.



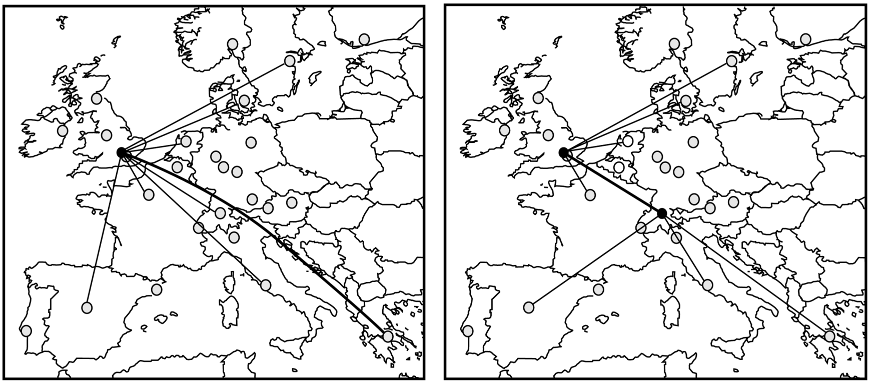
14.1 A 26-airport European airport system.



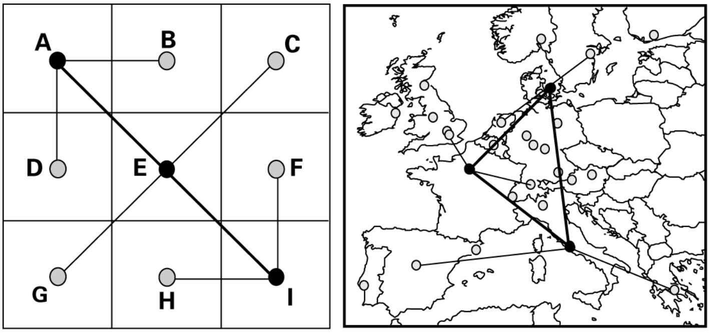
14.2 One-hub and two-hub airline route structure schematics.

14.4) can be seen to be a very unlogical looking physical configuration. Indeed, the commercial nonsense of this in respect of some destinations (especially Amsterdam) led to the study of even more complex route structures being abandoned. A simple tool had led to a very definite set of views on the pros and cons of route structure very quickly.

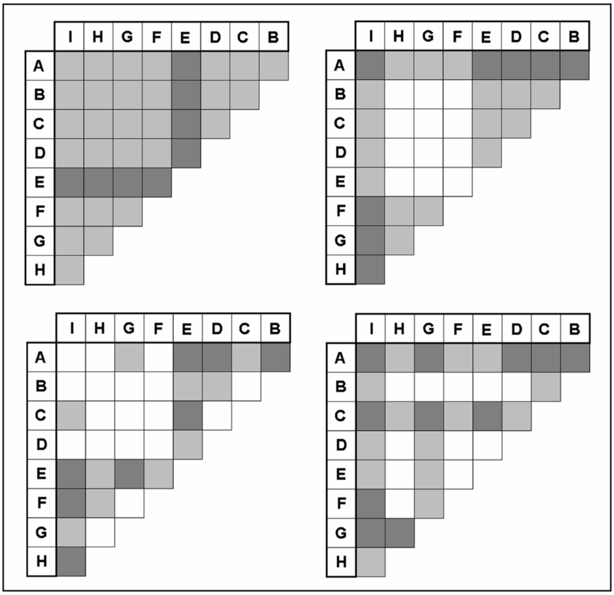
The tool also offered a fast assessment of routeing options available to passengers. The tables in Fig. 14.5 show the city-pairs served, a dark box showing a direct service, a grey box showing a hub-transfer service and the empty boxes showing where a single-transfer operation is not possible. (This has been constructed for a one-, two-, three- and four-hub network). The dilemmas of route analysts are well illustrated (and by corollary, the dilemmas of the teaching aid designer too, as the ability to create and analyse complex rather than just simple route structures is an oft-expressed requirement).



14.3 One-hub and two-hub route structures on a European map.



14.4 Three-hub airline route structure: schematic and actual.



14.5 The shaded squares show city-pairs served directly (dark grey), indirectly (light grey) or not at all (clear). The four situations considered are: top left, one hub (hub airport E, as shown in Fig. 14.2, left); top right, two hubs (hub airports A and I, as shown in Fig. 14.2, right); bottom left, three hubs (hub airports A, E and I, as shown in Fig. 14.4); bottom right, four hubs (hub airports A, C, G and I, i.e. 'corner' airports with two non-corner airports served from A (these are B and D) and one airport each served from C, G and I (these being E, H and F respectively), which is not illustrated in other figures).

A convincing test of a paradigm that integrates so many viewpoints would be if it showed the limits in which solutions can be anticipated, and thus where research might bear most fruit. The air transport system, being a service industry, must have the ability to withstand an onslaught from external influences. The final paragraphs are therefore devoted to reviews of five well-forecast possibilities. These attribute-led considerations pave the way to applying the process model that has been created around the principles used to integrate viewpoints throughout the book.

14.4 Shift in the safety paradigm

Faced with the dilemma of more frequent headline-capturing events in operations, perhaps reaching the stage where there will be a fatal air transport accident per week worldwide, it has become pertinent for regulators to debate whether the industry's perceptions of what is classified as safe and unsafe needs an overhaul, and, if so, what impact any such shift might pose for the businesses.

14.4.1 Manufacturer

While the underlying processes that assure safety have not been changed in many decades, the way that legislation is being linked to the tracking of performance in service is becoming ever more useful to wring the best 'on-condition' approved capability from in-service aircraft. This is not new; the mandatory occurrence procedure (MOR) has long been a vital feedback indicator for the regulator.

An extension of this philosophy has been the introduction of certifiable operating procedures, such as ETOPS-clearances, which are handled almost as dispensations, in that the certified capability is monitored and if evidence does ever show that the risk-assessment assumptions are infringed the certification process has to recommence. There is a wave of thinking that, because of the vast amounts of data available from on-board health-monitoring systems nowadays, this could be the start of a new way of handling the certification and continuing compliance of an aircraft (systems and aero-engines included). Safety will not have changed it nature, just its complexion.

Safety regulators have begun to debate whether there will be a need to overhaul the industry's perceptions of what is classified as safe and unsafe, given the potential for public concern associated with the dilemma of more-frequent headline-capturing catastrophic operational events. At the time of writing there is a strong feeling that tightening technical requirements will probably do little to improve safety performance and that using on-condition compliance monitoring will be the best way to handle the

technical contribution. The manufacturer does not abnegate to the operator to improve operational safety, but does depend on a close enough association for the airlines to propose ways in which design can minimise the possibility of human-crew errors in service.

14.4.2 Airline

Airlines tend to be the organisations that face the brunt of public disquiet when safety issues become a cause of public debate. It is the airline's name and flight number that newspapers quote when an incident occurs. In some respects they are passenger, even hostage, in the dilemma.

Safety is a perceived quantity, and the philosophies that have guided businesses to adopt processes and procedures that achieve requirements have been outlined in Chapter 3. Some recent changes, in implementation rather than in scale, have been described above. It is well recorded that the accident rate is patchy, with generally slightly better averages in the most well-equipped regions, and it is because the lesser equipped regions are where services are developing most rapidly that the regulators ask whether current situations can be improved. The solution can be achieved in one of two ways – improve the infrastructure overall or change the benchmarks.

Moving the benchmarks is probably the most fundamental and least likely development. It means that an aircraft developed and certified today might not meet certification standards in the future. It will limit the possibility of manufacturers to offer commonality to an airline over several variants of a type, and that could impact the airlines' financial targets. This is not impossible (some long-gone regulatory changes have had an equivalent impact). The example most likely to be quoted is that the industry has done this in the past, to the extent that if an attempt is made to recreate an old-time classic as a modern replica, the details of design and equipment specifications have to be changed to meet modern needs. What does survive, and what does still fly, does so on dispensations, and the safety of the operations they perform is trusted to mechanics, technicians and aircrew whose knowledge and skills are complemented by a degree of diligence that has to be trusted.

The people in these roles, more often than not, are the role model for the kind of risk-takers that the industry needs to create through its imbued safety culture. It is widely accepted that rules will change, as new materials and systems evolve that will lead to change. Thus the almost imperceptible creep in legislative rigour that has occurred in the past will continue in the future.

The harmonisation of safety records throughout the world is a well-rehearsed process, and it is the front line of attack to address the most problematic safety situations that are being identified at the current time.

The accepted way to achieve acceptable performance is through offering the infrastructure, the training and the disciplines that are required across all safety-related areas of activity. The monitoring and reporting of activities and the acceptance of an operational culture that will accept the findings of investigative procedures is paramount to the spread of acceptable performance. The initiatives that contribute range from crew resource management (CRM) for aircrews, and similar programmes for ground-operations staff and engineering teams, to more general awareness campaigns. These will see people with indirect interests encouraged to ask rather than accept the edicts that seem to offend their own perceptions of what safety will entail.

The training processes that are used are being refined and improved continually, but getting training material into hundreds of languages, keeping it up to date and distributing it equitably throughout the world is a challenge in itself. The properties of modern information technology systems promise a better chance of success against these aims than anything hitherto.

14.4.3 Airports

Airport safety regulation has been reviewed root and branch as the 21st century has dawned, the flagship initiative being the ICAO Airport Certification programme. It has had some notable physical impact, with the extension of runway end safety area (RESA) requirements to 240 m, providing a prime example of how they seek to move the goalposts (in a positive sense). They are also likely to encourage investment in more airport-based safety aids (for example runway incursion protection), but this is an implementation that requires airspace service provider implementation.

Overall, the adoption of safety-led audits with wider application of hazard analysis and risk-assessment methodologies has become mandatory. There is a similarity to air-vehicle progress, where safety-related sensors have proliferated. The need for more reliable information on which to base decisions could precipitate a wider acceptance of comprehensive system health – and situational (including weather) – data-collection systems.

14.4.4 Airspace

Safety implications in this area come from the way that the infrastructure is developed. It is expected that it will be delivered in two phases: first, on the aircraft and, second, through operational support and associated procedures. The infrastructure on aircraft is already mandated. There could be more to come, but the operational infusion of what is available, and already

only elementarily used, suggests that this is the enabling area where further progress is, for some time yet, unnecessary.

Compared with aircraft only 20 years ago all airliners nowadays have communication, navigation and surveillance (CNS) capability that can allow them to communicate from any location (Sat-comm, ADS-B or Mode S) and to navigate accurately (GPS primarily, with dissimilar redundant back-up, such as laser-based inertial navigation systems (LINS)). The existing ground-based navigation infrastructure of VOR, DME, ILS, etc., will be reduced as time goes by, but is unlikely to disappear, as it is also an independent reference for on-board systems. Surveillance is an expanding field, with ADS-B especially opening the possibility that the whereabouts of every aircraft will be known with superb accuracy (not just to the ATC staff on the ground but to all aircraft around), within a short space of time.

The capacity dilemma will soon be averted if reduced separation standards are introduced, but this will mean that safety in the operation will be even more dependent on 'automation', such as conflict-detection systems.

Airspace management is provided the world over, and in some impoverished communities (this could be a remote country or one recovering from war or cultural upheaval) the aircraft that will appear in its airspace will have the appropriate systems on-board to operate much more efficiently and effectively than the system can support. This can create a 'weak-chain' effect in respect of long-range operations, as the planned demand on the route(s) must respect this lowest capacity level. Equipment will be the key to achieving a greater consistency of performance in such cases, but staff knowledge, skill and attitudes will be where the battle of hearts and minds that will deliver the best combination of safety and performance is won.

14.5 Shift in the environmental impact paradigm

Of all the postulated scenarios, this is the one where there is greatest uncertainty. The impact of aircraft noise on communities has long been recognised and very strenuously regulated. It is not inconceivable that the current day standards will be revised further in the near future. The perception in many segments of communities is that more of a similar nature has to be done by aviation to alleviate equivalent impacts, such as air pollution. This is an area where cause and effect are so often confused, because constraining operations just to meet a limited number of arbitrarily selected criteria can impact the ability to meet other societal requirements. Argument has to address the impact of transportation on all aspects of life in communities, and ensure that aviation and its role in the local situation is

handled in a manner that balances what is delivered and what is imposed by all contributory factors.

14.5.1 Manufacturer/airline

Environmental impact is inevitable and the aircraft design and operating teams are rarely out of each other's sight on this topic. Gaseous and noise emission improvements will come from the technological developments covered in the previous chapter. Airlines should be encouraged to use the best aircraft, in terms of environmental impact, and it would be wise to consider incentives rather than disincentives to achieve this aim.

Gaseous emissions are inevitable while aircraft use combustion technology. At this point in history a non-combustion air-vehicle, with useful properties (speed as well as payload and range) is not in prospect. The nearest solution is the airship, but operational issues stemming from the meteorological aspect of operations, handling and much more need to be addressed. There is something positive to be said for using lighter-than-air vehicles in freight operations, as trade in goods is often the most important national economic cross-border activity. The long-term benefits from such a development, while they present problems in the short term, cannot be refuted without debate.

There is also room to debate the effect of gaseous emissions in the stratosphere, where the air is more rarefied than at sea level and the global circulation created by weather systems does not draw such air down to sea level very frequently. There has been little evidence to show that this is a significant issue, but it can be assumed that if it is there will be governmental-level interest in finding ways of alleviating any tendency to accumulate gases that will cause atmospheric effects of a 'greenhouse' nature.

In the days after the 9/11 attack on New York in the USA, all air traffic was curtailed for several days, and there were reports of very different atmospheric conditions attributed to the lack of water-vapour contrails. If this proves to be true then lower-altitude operations may be considered as a cure. Using current-generation jet airliners this would be a solution with financial, efficiency and effective service impacts. Indeed, it could lead to more direct gaseous pollution and it would certainly contribute to an airspace capacity crisis. While research proceeds, with governmental support, in scientific academic departments, there is no clear route for their results to be digested in engineering and social science faculties, where the impact of postulated change can be fed into industry-sponsored programme-related research. This is a prime example of a lack of 'systems thinking' in the efforts spent to develop a future viable air transport community.

As airlines are there to serve communities and passenger demand is growing inexorably, the environmental impact dilemma is that whatever is said about the effect of operations, in terms of noise and gas pollution, the demand will continue to grow. The question has to be asked whether taxation will be an effective palliative to the potential overuse of aviation. It has not been a particularly effective way of controlling the growth of demand where other addictive pursuits have been targeted. Using aircraft to fly on journeys that are desirable but not necessary is just another example of addictive behaviour.

Environmental improvements will come through initiatives shared by aircraft manufacturers, airlines, airports and air traffic service providers, who will be certain to use the most efficient technology, and as effectively as possible. The airlines will face demand that will only show signs of diminishing if other transport modes take a slice of their existing markets, and they can thus expect that the press coverage of their activities will simply continue to be negative.

A simple initiative will be 'bio-fuels', whereby the hydrocarbon content of the fuel tanks will be generated from 'renewable' – thus organic – sources. This is not as environmentally effective as is often presented, as simply burning reconstituted plants rather than burning the extracts of fuel that has been pumped from underground simply reinforces the link to the combustion of hydrocarbon fuels. Certainly, oil will run out one day, and if and when that day comes, the alternatives, because they will be available and renewable, will be much prized. The demand for them to conduct necessary duties, such as heating hospitals and other essential amenities, is sure to take priority over aviation. Civil aviation might also be further down the queue than military aviation.

The core part of aviation cannot link into renewable energy from sources such as wind-farms and tidal energy extraction, although offices and other activities can subscribe to energy suppliers who offer such eco-friendly services.

Airlines do not have much comfort to offer environmentalists, apart from promising to find the best way to minimise the emissions they generate. The public have to be persuaded, or prevented, from flying on airlines in order for any significant change to occur. They will, almost certainly, sign up to 'carbon credit' schemes, whereby they support the creation of forests that will absorb carbon dioxide at a rate equivalent to that at which they generate a so-called 'carbon footprint'. This is fine, but the world's hungry populations want land for agriculture and have actively destroyed forests at an alarming rate for many years. Finding the land on which to continue such work will become more difficult as time goes by.

14.5.2 Airports

The environmental situation with regard to airports is never likely to be anything but adversarial. An airport, while it has a small 'footprint' on the landscape, has a sizeable 'noise footprint', which really has no exact limit. There is not an 'edge' beyond which there is no noise, and wherever there is any noise, a noise objection is almost certain to be heard.

This has meant that all significant airport developments need to be supported by an environmental impact statement (EIS), and the scope of such documents is becoming greater all the time, thus covering noise, air pollution, effects on flora and fauna, issues of access and intrusion. Some of these are relatively subjective properties that are difficult to define and measure with the degree of precision that is desirable.

If an environmental objection is upheld and it places a cap on the capacity of an airport (either runway or ground facilities), services will no longer be able to originate from where the demand is located. This could encourage more ground-transportation usage to one or more neighbouring airports, which will have an environmental impact that will be just as unwelcome. The airport and environmental issue, more than most, cries out for a holistic solution.

14.5.3 Airspace

Sometimes the question is asked: 'Should ATC be legislated to reduce the incidence of contrails?' This has yet to be taken seriously because if it were to be implemented, the available capacity will fall dramatically.

A very serious interest is expressed by air traffic service providers to moderate TMA operations (using the ground-based ATM computers coupled via data-link (e.g. Mode S) to the aircraft FMS) to improve climb and descent performance. This has the potential to reconcile emissions, fuel-burn and noise impact, and could bring considerable environmental benefits.

An issue to address, with an eye on the way that demand will be generated within the natural environment, is if large airports are shunned, the result could be the expansion of more, smaller, airports. There is the likelihood of more services from the door, so landside pollution is minimised, but as the brief analysis of route structure attributes has shown, the chances of getting anywhere without a transfer at a major hub is then often almost remote. The point is reached too, where ATM teams, presented with more smaller aircraft flying to/from more dispersed airports, will be hard pressed to coordinate all of the movements.

14.6 Using additional larger aircraft

This is the solution that has been followed through in successive generations of air transport development. From when aircraft with a few passengers plied between major centres to the modern day, when there can be many more flights by much greater capacity aircraft, there has been an assumption that the 'next-generation' aircraft will be larger capacity.

14.6.1 Manufacturer

When aircraft of similar technology are compared, the larger the aircraft used within a similar operational context (annual utilisation, stage lengths, etc.), the lower will be the operating cost per seat. This has been at the crux of all development throughout aviation history.

In the early jet era the largest airliner was the Douglas DC-8-63 (256 seats), which was eclipsed by the Boeing 747-100 in 1970, with roughly 400 seats. While there was a 10% or so increase in cabin space in the later 747-400 (late 1980s), that was the largest aircraft in production for almost 40 years. Since November 2007 the largest aircraft in service has been the Airbus A380, which offers, in roughly like-for-like seating arrangements, about 50% more passenger capacity than the 747-400. It is right on the limit that airports will accept. A design objective for the A380 was to better the 747-400 seat operating cost by 15%.

There are over a thousand 747s in service (mostly 747-400s) and approaching 200 A380s on order and just entering service, as these notes were written. The sales rate of the A380 has faltered, but most analysts expect it to pick up, while interest in further 747 derivatives, although it offers a lot of commonality with the existing variants, is proving hard to find. The likelihood of seeing the vast investment that is necessary to create a further very large aircraft (VLA) design makes the possibility of seeing any larger capacity aircraft almost inconceivable in the near future.

14.6.2 Airline

Airlines will usually queue for a lower operating-cost aircraft. The fact that sales of very large aircraft have not met what seemed to be very realistic analytical forecasts does signal that some new thinking is taking place. The majority of the early batch of A380 operators are airlines that compete with one another, so in 'domino' style, as soon as one has fallen for the type another decides to opt for the same aircraft. If route structures remain unchanged, history suggests that the aircraft will see an order surge from new customers in the near future. If route structures do change, there will be a shift in purchasing patterns that could see the A380 production rate

dwindle. It was recognised to be a big statement of faith, that could so easily go wrong, and commercially Airbus is nursing a very eligible, but expensive and only cautiously accepted, baby.

If airlines choose to stay with the 747 for a while longer, they will have small A380 fleets, and the costs for upkeep and maintenance of the latter will be more critical than for the 747, for which there are many maintenance locations. This is one reason why, even though an A380 costs in the order of $250 million per example, the airlines that choose the type will tend to buy a sizeable fleet. In such a situation, route strategy can be predicated by the fleet capacity. Of all the stakeholders with an interest in larger aircraft, the airlines are the key player. They hold the right to choose or not to choose to go that way at the moment. If they do not choose the larger aircraft they will have to buy more smaller aircraft, unless they change route strategy, because it could be that they can carry more people directly. The manufacturers are lining up that choice, and it is perhaps the most crucial future decision for all airlines, especially in long-haul but eventually in short-haul too.

The latter comment deserves some thought. There has not been a direct technical challenge involved in offering direct or indirect routes. However, any analysis of regional airports in Europe, and especially in the UK, Italy and Germany, where EU-inspired route liberalisation has had the greater impact, will show the destinations directly served to have grown considerably. There is a belief that this is low-cost airlines opening new markets. There has been a counter-claim too, by the UK CAA, that there has been no significant acceleration in the growth of UK air travel over the same period, and while this was a surprise to many analysts, the news is that more people are flying directly, rather than through hubs. Some regional hubs in Britain – Manchester and Birmingham – have had successful trading years with new routes (often medium- and long-haul), but with lesser growth than surrounding airports, such as Liverpool, Leeds Bradford and East Midlands. There has been access to fleets of aircraft of typically 130–180 seat capacity that could open the direct markets from the smaller regional airports. It could be relieving the bigger regional airports, which in itself could be an example of the 'direct is better than transfer' trend that has been long forecast. At the moment the moves are masked by low-cost airline fare strategies and the fact that the new low-cost airlines are cherry-picking routes, offering seasonal schedules to well-established destinations (or smaller regional airports where the more well-known destinations are already capacity-strapped).

14.6.3 Airports

The preceding comments on airline developments have already reflected directly on airports. Where larger aircraft have been used there has been a

reduction in the rate of increase in movements, even when passenger totals have increased. The airlines have simply lifted the passenger per movement figure.

Generally, this requires reinvestment by airports in larger facilities. Because much of the growth has been generated by low-cost airlines – in Europe, the USA and more recently in SE Asia – the reinvestment has been as meagre as possible. The biggest push has been to develop larger car parks, recognising they are essential to the people using the new services and that they are a relatively low-cost but high-revenue addition to the airport infrastructure. Where airports have been most economical has been in the way they have accepted there will be a reduction in customer service quality, with crowded concourses and lounges, long security queue, and so on. It is debatable whether the general public will accept this as a long-term solution. Low-cost travel has been extremely low-cost, and there is a feeling, certainly in Europe, that people will pay more for a better service.

Beyond the terminal, the apron is often the next most important area to study at an airport. If the airport has invested in fixed passenger-handling facilities (air-bridges in particular), they will have been set a fixed distance apart, which might not accommodate larger aircraft. This has not been a problem at regional airports, where the aircraft size has been almost static, but at larger international airports the advent of the 600-seat plus aircraft does not just pose a huge logistical problem but also a question about where to locate them. If new stands are added at the periphery of existing facilities, the newer aircraft are long walking distances away from the terminal facilities. Reorganising existing facilities takes capacity out of the airport while the transition is being conducted. The juxtaposition of the four principles in the strategies available to airport management teams is particularly problematic, and could be one area where the airports will begin to make inroads into airline strategies, for without a balance of on-board and airport-based service qualities, no airline can really afford to upsize.

On the whole airports should be expected to welcome larger aircraft, but the case for them is not overwhelming. It is widely regarded at international airports, where congestion is an existing or looming dilemma, that larger aircraft are inevitable, and at these airports they will almost certainly be welcomed.

14.6.4 Airspace

The same arguments that apply to airports must also apply to airspace development. They are an equivalently capacity-strapped element of the system, albeit they have fewer constraints on how what they offer is used. Within the capacity-allocation processes an ATC ‘slot’ can be allocated to any size of aircraft, and the choice as to whether it will be occupied by a

large or small aircraft is almost entirely up to the operators. There are capacity issues with regard to airport access, as a very busy airport may find that increased separation for vortex-wake protection reduces 'slot' capacity. The tailoring of slots to serve an airport is already an issue on which airports and airspace service providers consult one another, and while the decisions are primarily made with financial implications in mind, where the other principles intrude, they begin to affect the judgements that predicate solutions.

In general, an airspace provider has to assume that larger aircraft means fewer movements for a given level of demand, and they must welcome any move towards larger aircraft. They have to believe that congested hubs will be relieved, but the likelihood is that movement rates will not diminish at large airports. Meanwhile, if more direct flights are handled in smaller aircraft, the implication can be that ATC services will become more overwhelmed in the en route airspace sectors.

14.7 Relieving hub congestion with more point-to-point services

This is the corollary scenario to using larger aircraft. This scenario is not easy to present or assess. To illustrate the points that need to be considered, an elementary view on the situation has been offered in Chapter 1. The impact of offering an operational solution that meets this aim, in whole or part, is likely to impact all the elements of the air transport systems – aircraft manufacturers, airlines, airports and airspace service providers. Common viewpoints, and perhaps common nomenclature, will need to arise before common ground can be found on which objective study can proceed.

14.7.1 Manufacturer

The promotion of this strategy, although an airline-based development, has been championed by a manufacturer – Boeing. As they lose market share in the large aircraft sector their promotion of this concept can be cited as self-interest. However, they have recognised that this trend will be inevitable in some markets, and they have tailored their next-generation aircraft to utilise technology in such a way that the flexibility it will offer to an airline will suit it to supporting such change. They have been so successful with initial sales of the new product – the three-model 787 range – that they have the satisfaction of seeing their main rival introduce a new aircraft model – the A350 – which is aimed at the same payload–range sector and utilises similar technologies to offer similar operational attributes. The customers – airlines – are saying that these types offer a new era, in long-haul travel at least.

14.7.2 Airline

In stating that they will invest in aircraft that, potentially, will be 'hub-busters', airlines are balancing the four principles as delicately as ever before, and in some respects stating that they will equip themselves to enable radical solutions to pending capacity crises.

It is widely regarded that airlines will use large aircraft where hub demand is still large, and they will also relieve hubs. There is no better example of a situation where one element of a system is investing in flexibility that the other elements can use to their own advantage. The degree to which they have been empowered to take decisions that will realign priorities in the business is the prime reason why there has to be an expansion of cross-disciplinary debate.

14.7.3 Airports/airspace

These are the two service elements in the system and are equivalently affected by the move to/from large/small and direct/indirect route options. There is a tacit assumption that increased demand will improve utilisation, but being service elements they are at the mercy of the airlines to relieve hubs and to distribute demand equitably. This will not happen, because the service provider will distribute services to serve demand from wherever it is recognised. There is bound to be a lack of homogeneity about transport demand and thus a lack of regularity in the demand that faces airports and airspace provides.

The airports will, almost certainly, remain tiered into small, regional and international categories. The attributes expected of them to fit strategic decisions on service quality (and price) determined by airlines will impact everyone, and airports in particular. How the airports respond, and whether they integrate policies more openly than they do currently, will determine many of the key features of future services. There are many options, and no clear evidence of which way this debate will go.

The still patchy distribution of demand and the way that en route routes merge and cross are difficult issues for the airspace providers to accommodate. The ATM community will want to field a system that is up to expectations, but without associated research to find the parameters that can be traded to define optimal solutions there is little chance of success.

14.8 The threat of more attractive modes of transport

This is a scenario that regards aviation as facing a threat from surface transportation travel modes. It might be pertinent to consider what threat aviation presents to other transportation modes. When speed, convenience

and the life-cycle cost of solutions with differing capital and operations expense profiles are compared, the situation is less clearly stacked against aviation. The business has to manoeuvre itself into a mood of greater self-confidence, and it may find that the fight is much less one-sided than initially appears.

14.8.1 Manufacturers/airline/airports/airspace

When an external influence of such magnitude is considered, the viewpoint differences between the elements almost coalesce into one, as the elements can be expected to stand together as an 'industry'.

Consider the impact of the Channel Tunnel between Britain and France on UK–European travel habits. If either the rail or aviation perspective is taken, any sources of data consulted will suggest that the side considered is the 'winner'. The simple fact is that there has not been a 'loser' until a very non-business view is taken and the question is asked: 'What it is that maintains a continuous rise in demand?' At the moment, environmental impact is clearly not influencing travel choices among European populations. There are several aspects to consider, as in many ways there is an easy argument that the demand will rise still further, perhaps even faster, and so much so that capacity issues will arise again. The surest way of sowing seeds of doubt over the ability of the system to cope with future demand is to use the USA as a benchmark.

There are still many more journeys undertaken per head of population in the USA than there are in Europe. If it is assumed that the USA experience is a plateau that Europe will reach, then there is a lot more demand to come. If it is accepted that the USA has a greatly inferior surface transport system than Europe, there is a case for the demand for air services to be less in Europe than it is in the USA.

If European governments (national and EU) view their travel forecasts and decide to build an environment to accommodate it, they have to decide how they apportion the facilities and costs. Building a high-speed rail system requires a lot of land – more than building (or especially expanding) a few airports. The land-use is throughout and between communities, so it has a direct impact on many people, and the 'noise' blight is equally invasive throughout communities. Ask contractors to build a new airport and they will queue up, perhaps even offering to finance and enter into build, operate and transfer (BOT) contracts, but ask them to build a new rail system and they will be much more cagey. The costs (building and running) are much greater and the facility has a very well-defined capacity. Ironically, good rail system access can be excellent news for an airport with a railway link; see the diagram in Fig. 2.3 in Chapter 2 of the distribution of demand across the

UK for services at Birmingham Airport, which has a high-speed railway station directly linked to the airport terminal.

Airspace service providers can be more relaxed. If railway services expand, they will moderate the growth rate of air transport, which could be interpreted as relieving congestion.

14.9 The case for more widespread systemic thinking

It is difficult to know where to stop when analysing the attributes of a system. In this book the view has been that civil aviation is a system whose properties can be analysed and managed to meet the needs of operators, investors, users and many more people. That in itself is a broad mandate.

In the preceding pages of this chapter the desire has been to show that, while the topic is complex, a way of making its exploration possible, in class and in research terms, has been very definitely recognised. Insofar as it has been developed, its value is proven, but the path that needs to be trodden has barely begun.

Additionally, in attaching some debate to five case studies – which any air transport manager trainer is recommended to consider – some system attributes showed that some will be easy to relate to through systems modelling and some will not. Safety is an example in the latter category, but delving into the realms of whether an airline uses larger aircraft and stays wedded to hubs or uses longer-range aircraft and pioneers more direct services is an aspect of development that will lend itself to analysis through models. The breadth of these will need to be much wider than those that already exist and that stay close to technical optimisation. The four principles of the book have explained what scope there is to find a set of worthy and useful optimisation characteristics.

Over 40 years after the author first set foot in air transport operations (in an ATC centre amid fields and without an aircraft in sight, nor a radar screen in the operations room) the business has never failed to reveal a sense of being too big to really understand. The years have introduced contact with many individuals and organisations, and the overwhelming message has been that everyone, invariably, has enjoyed the business, yet wrestled too with knowing where to place the boundaries.

In setting out some views on how this might be achieved, one ends up – in debating surface modes of transportation – looking outside the proposed boundaries and even debating across a wider scope. This is not untypical, and the voice has to trail away when it comes to considering such wide-ranging debate in any depth. There will be multi-lateral debates that can impinge on air transport, some of it from within governmental policy perhaps, some more than likely from investment sources. They will carry tales of social and economic aspiration, and while these remain vigorous

they also remain challenging to the industry's leaders and decision-makers. The latter will profit, in every domain, if they have around them strategic and tactical management teams that can speak more confidently of these challenges. The assistance they need, it is believed, is in structuring their own concerns and having the right to be non-conformist while still conforming to a framework that will support the construction of robust and enduring solutions. Systemic thinking has the power to deliver that, without diluting the qualities of the disciplines addressed, and the power to do it is within everyone. Recognising the need, before the consequences of neglect are that the business itself is bounded, is a responsibility to share.

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